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Return-volatility linkages in international equity and currency markets

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Suomen Pankki
Bank of Finland
P.O.Box 160
FIN-00101 HELSINKI
Finland
☎ + 358 9 1831

http://www.bof.fi

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* College of Business Administration, University of South Florida, Tampa, FL
** SOM, N.J. Institute of Technology, University Heights, Newark, NJ and research department, Bank of Finland
*** College of Business Administration, University of South Florida, Tampa, FL

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Abstract

This paper, which is motivated by the literature on international asset pricing and recent work on exchange rate determination, investigates dynamic relationshiops between major currency and equity markets. Using a multivariate GARCH framework, we examine conditional cross-autocorrelations between pairs of national equity markets and related exchange rates. This provides a parsimonious way of testing mean-volatility relationships in currency and equity markets and re-examining the robustness of relationships between equity markets, while controlling for exchange rate effects. We find that the relationship between currency and equity markets is bi-directional, significant, persistent, and independent of the relationship strictly between equity markets, and that it is better captured by the conditional second moments

Key words: international asset pricing, exchange rate determination, equity markets, relationships between currency and equity markets.

JEL classification numbers: G12, G14, G15, F31

Kansainvälisten valuuttakurssi- ja osakemarkkinoiden tuotot ja volatiliteettien väliset suhteet

Suomen Pankin keskustelualoitteita 9/2002

Bill B. Francis – Iftekhar Hasan – Delroy M. Hunter
Tutkimusosasto

Tiivistelmä

Tämä keskustelualoite on osa kansainvälistä varallisuuden arvonmuodostusta ja keskeisten valuuttakurssi- ja osakemarkkinoiden välistä dynaamisia suhteita koskevaa tutkimusta. Moniulotteisen GARCH-mallin avulla työssä tutkitaan ehdollista ristikorrelaatiota kansallisten osakemarkkinaparien ja niiden keskinäisten valuuttakurssien välillä. Tällä tavoin sekä kansallisten osakemarkkinoiden että niiden ja valuuttakurssien keskiarvon ja volatiliteetin väliset suhteet voidaan selvittää entistä tarkemmin. Tutkimuksemme osoittaa, että valuuttakurssi- ja osakemarkkinoiden väliset suhteet näkyvät parhaiten ehdollisissa toisissa momenteissa eli volatiliteeteissa. Nämä suhteet ovat kaksisuuntaisia, merkitseviä, pysyviä ja riippumattomia pelkkien osakemarkkinoiden välisistä suhteista.

Asiasanat: kansainvälinen varallisuuden arvonmuodostus, valuuttakurssien määräytyminen, osakemarkkinat, valuuttakurssi- ja osakemarkkinoiden väliset suhteet

JEL-luokittelu: G12, G14, G15, F31

Contents

1 Introduction

In a recent BusinessWeek article entitled "The Currency Game Has Brand-New Rules," it was noted that a quarter-point increase in the euro zone interest rate by the European Central Bank defied convention when the euro declined against the dollar. However, the announcement that the $183 billion dollar takeover of Germany's Mannesmann by the British mobile phone giant Vodafone AirTouch PLC caused the euro to increase by 2.5 cents against the dollar.[1] The article noted that the impact of deals and stock prices on exchange rates became "powerfully apparent" in 1999 when the yen failed to react to policy initiatives by the Bank of Japan but reacted significantly to stock and deal news. On the other hand, the impact of the currency market on the equity market is highlighted in a BusinessWeek article that partly attributes the recent underperformance of the U.S. stock market to the third-quarter 2000 downward revisions in earnings partly as a result of a weak euro.[2]

The importance of the above occurrences demands that we take a new perspective on the linkages between equity and currency markets. In particular, what is the impact of equity returns and volatility on exchange rate changes and volatility? Does the currency market impact equity markets in ways other than that suggested by international asset pricing models? And, is the relation between equity markets affected by unusually high currency volatility? The understanding of these issues is of importance to academics, investors, corporate treasurers, and regulatory authorities. In addressing these issues we combine aspects of the international asset pricing literature and the recent literature on the determination of exchange rates.

We make three contributions to the literature. First, we investigate the impact of exchange rate changes on the conditional first and second moments of equity returns. This provides additional insights on this relationship to that provided by theoretical asset pricing models and the most recent empirical work. Theoretical work by Solnik (1974), Grauer, Litzenberger, and Stehle (1976), Sercu (1980), and Adler and Dumas (1983), among others, show that currency risk should be a priced factor in explaining equity returns. Although theoretically appealing, early empirical tests (see, eg, Jorion (1991)) failed to find support for exchange rate risk as a priced factor in explaining stock returns. However, more recently Dumas and Solnik (1995) and De Santis and Gerard (1998) use conditional asset pricing models to show that currency risk (as measured by the conditional covariance between equity and currency returns) is important in explaining the variation in the *mean* of equity returns. While Williamson (2001) finds that exchange rate

[1] See BusinessWeek, February 21, 2000, p. 128.

[2] See BusinessWeek, December 4, 2000, p. 157.

helps to explain the mean returns of the automotive industry. Despite this evidence, Griffin and Stulz (2001) provides evidence that casts doubts on the importance of exchange rate changes in (industry-sorted) equity returns, thus necessitating the need for further analysis.

Along with investigating the relationship between the first moments we also analyze the relationship between the second moments. If in fact currency risk is a priced factor in equity returns, it follows that increased exchange rate volatility should lead to greater equity volatility. Although numerous studies have examined the dependence in volatility across international equity markets (eg, Hamao, Masulis, and Ng (1990), Lin, Engle, and Ito (1994), and Connolly and Wang (2000)) and across currency markets (eg, Engle, Ito, and Lin (1990)),[3] surprisingly little is known about how currency volatility influences equity market volatility.

Second, we examine the extent that exchange rate changes can be explained by changes in equity markets. This examination complements new evidence by Evans and Lyons (2001) on the importance of order-flow, a measure of buying/selling pressure, on exchange rate determination. Surprisingly, there is very little knowledge of how equity returns impact exchange rate changes. Most existing studies that examine the relation between equity and currency markets have in general, treated the exchange rate as exogenous. Presumably, this is the case because traditional theoretical models of the determination of exchange rates have not had a role for equity markets. However, as noted by Frankel and Rose (1995) and Evans and Lyons (2001), traditional (macroeconomic) models of exchange rates have been a failure in explaining exchange rate movements.[4] And as noted by Flood and Rose (1995) "… we are driven to the conclusion that the most critical determinants of exchange rate variability are not macroeconomic."

More recently, Evans and Lyons (2001) present an exchange rate model that explicitly incorporates determinants from the field of microstructure – order flow. Their results show that incorporating order flow as an explanatory variable in determining exchange rate changes results in R^2 statistics of over 50%. Because international stock markets are linked by equity market order flow, which in turn strongly influences currency order flow it is expected that changes in equity returns lead to changes in exchange rates. The casual empirical evidence above provides support for this channel of influence.

Finally, we investigate if the relation between international equity markets changes as a function of the changing volatility of the currency market. This is important for international asset pricing since Longin and Solnik (1995) and

[3] For equities see Gagnon and Karolyi (2000) and references therein, Karolyi (1995), Kim and Rogers (1995), King, Sentana, and Wadhwani (1994), Engle and Susmel (1994, 1993), King and Wadhwani (1990), and others; for foreign exchange see Bollerslev (1990), Baillie and Bollerslev (1990).

[4] As noted by Evans and Lyons (2001) "In sample R^2 statistics as high as 10 percent are rare."

others[5] show that equity market correlations change over time. And Dumas and Solnik (1995) and De Santis and Gerard (1998) find that incorrect inferences can be drawn if this time variation in correlation is not modeled. Empirical evidence provided by Roll (1988, 1989) and King and Wadhwani (1990), among others, indicate that increased equity volatility in one national market leads to greater correlation with other equity markets. The authors attribute this, not to increased integration, but rather to a market contagion effect.[6] Additionally, we investigate if the conditional correlation between two equity markets is impacted by higher conditional volatility of the exchange rates between the two economies. If in fact we find that currency volatility is significant in the future conditional variance of equity markets, then it is expected that increased currency volatility will cause the correlation between equity markets to increase.

We employ a trivariate GARCH (1,1) model (Engle and Kroner (1995)) to study the dynamic relations between currency and associated stock markets. Multivariate models are more efficient than their univariate counterparts in capturing intermarket dependence. Unlike the univariate model (eg, Hamao et al. (1990)), the multivariate approach incorporates the impact of both squared errors (shocks) and past volatility of one market on the current volatility of the other(s). This allows us to garner further insights of the relationships between the financial markets included in our analysis. In the current context, a univariate model is unable to investigate the currency-induced time variation in the correlation between equities. A representative model includes the U.S. stock market returns, the Japanese stock market returns (in local currency), and the yen/dollar exchange rate. Similar models are specified with the U.S. stock market, and the British and Canadian stock and currency markets, respectively.

We find that there are significant, bi-directional, short-run dependence between the major equity and currency markets. Specifically, our results show that past volatility of the exchange rate between the U.S. and each of the three domestic markets have a significant impact on the conditional variance of both the U.S. and domestic equity markets. This provides a possible explanation for the large number of studies that failed to find exchange rates having a significant impact on equity returns. That is, the lack of significance of past results maybe due to the failure to take into account the relationship between the second moments. Our results also indicate that past volatility of the equity markets predict the volatility of the currency market, but the latter is generally much weaker than the former.

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5 See also Roll (1989), Erb et al. (1994), Solnik et al. (1996), Butler and Joaquin (2000).

6 However, Forbes and Rigobon (2000) assert that these measures of correlation are biased upwards as they are conditioned on (increased) volatility. In the context of our GARCH model, this bias is adjusted for.

In contrast to the volatility results we find that in general, dependence in the mean within the various groupings is marginal. The notably exception is the U.S., Canada, Canadian dollar/U.S. dollar grouping where the dependence is generally from the equity markets to the Canadian dollar/U.S. dollar market. Moreover, the volatility "spillover" between the U.S. and the other major equity markets reported in previous studies is still present even after accounting for the exchange rate effect. We also find that the strength of the relationship (in the second moments) between currency and equity markets has increased substantially since the 1987 stock market crash. Finally, it is generally the case that higher exchange rate volatility causes the correlation between the U.S. returns and the returns on the Japanese and U.K. equity markets, respectively, to increase.

The remainder of this paper contains four sections. Section 2 outlines the methodology and section 3 describes the data and descriptive statistics. We present the empirical results in section 4. The paper's summary and conclusions are in section 5.

2 Empirical methods

The first set of tests in this paper uses the parsimonious BEKK representation of the GARCH (1,1) model (Engle and Kroner (1995)), which guarantees a positive conditional variance. More specifically, the model employed to estimate the cross-market dependence in mean and volatility has the following representation, respectively:

$$R_t = \Psi_0 + \sum_{l=1}^{L} \Psi_l R_{t-l} + e_t \qquad (2.1)$$

where $e_t | \Omega_{t-1} \sim N(0, H_t)$, and

$$H_t = C'C + \sum_{p=1}^{P} A'_p e_{t-p} e'_{t-p} A_p + \sum_{q=1}^{Q} B'_q H_{t-q} B_q \qquad (2.2)$$

where $R'_t = (R_{1t}, R_{2t}, R_{3t})$, are weekly returns on, say, the U.S. stock market, the Canadian stock market, and the change in the Canadian dollar/U.S. dollar exchange rate, respectively; $\Psi'_0 = (\psi_{01}, \psi_{02}, \psi_{03})$ are constants, $\{\Psi_l\}_{ij} = \psi_{ij,l}$ where the i,jth element of Ψ_l indicates the effect of, say, the change in the Canadian dollar/U.S. dollar exchange rate on the Canadian stock market in l days. The residuals from the conditional mean equations are $e'_t = (\varepsilon_{1t}, \varepsilon_{2t}, \varepsilon_{3t})$.

C is a 3×3, upper-triangle matrix of constants. A and B are free matrices defined as $\{A_p\}_{ij} = a_{ij,p}$ and $\{B_q\}_{ij} = b_{ij,q}$, where p and q are the appropriate lags. In this specification the conditional variance coefficients $a_{ij,p}$ and $b_{ij,q}$ are squared. We report absolute values, $|a_{ij,p}|$, not their squares. Several covariance terms are not reported since they do not impact on the results. In the non-diagonal model used in this paper, stationarity is not necessarily violated if a particular coefficient is greater than one. For the GARCH(1,1) model weak stationarity is met if the eigenvalues of $A_1 \otimes A_1 + B_1 \otimes B_1$ are less than one in modulus.

To investigate the effect of higher-than-average currency volatility on the correlation between equity markets, we use the following trivariate GARCH(1,1) model that is an adaptation of the conditional correlation model of Bollerslev (1990). The following specification allows for time-variation in the conditional correlation (equation (2.5)):

$$R_{i,t} = b_0 + X'B + \varepsilon_{i,t} \tag{2.3}$$

$$h_{i,t} = c + a\varepsilon^2_{i,t-1} + bh_{i,t-1} \tag{2.4}$$

$$h_{ij,t} = (r_0 + r_1 FXVOL_{t-1}) * [\sqrt{h_{i,t}}\sqrt{h_{j,t}}] \tag{2.5}$$

where for the conditional mean and variance (equations (2.3) and (2.4)) i = 1, 2, 3 (the U.S., the foreign equity market, and the currency market, respectively). In the conditional covariance equation (equation (2.5)) i = 1 and j = 2. FXVOL is an indicator dummy variable in the covariance between the equity markets. It takes the value of one if the estimated conditional variance of the respective exchange rate (h_i for i = 3 in equation (2.4)) is greater than its unconditional (long-run average) value and zero otherwise. The unconditional volatility is calculated in the usual manner (h = c/(1–a–b) from an estimated equation system (not reported) where the exchange rate-induced asymmetry is omitted. The vector X contains own lags.

Equation (2.5) is the conditional covariance model where r_0 is the estimate of the constant correlation between each pair of assets. The coefficient r_1 is the conditional correlation between the two equity markets. For parsimony, only the conditional covariance equations involving the two equity markets contain the time-varying correlation. That is, the covariance equations involving equities and exchange rates model the correlation as a constant. If the coefficient r_1 is non-zero, then the correlation between major equity markets varies over time as a function of higher-than-average exchange rate volatility.

To estimate the coefficients in the above models we maximize the log likelihood function from the conditional normal specification but calculate a covariance matrix of the parameters that is robust to the distribution (eg, non-normality) of the errors (ie, a quasi-maximum likelihood (QML) approach similar to Bollerslev and Wooldridge (1992)). Model diagnostics, coefficients, and graphs of the conditional variances (not reported) are used in the selection of the final specification. The multivariate Schwarz Bayesian Criterion (SBC) is used to decide on the final model if all specifications are acceptable with respect to the above criteria.

3 Data

We use weekly returns in local currency for the U.S., Japanese, British, and Canadian stock markets and the exchange rate of each country with the U.S. dollar. The data are obtained from the Morgan Stanley Capital International (MSCI) database. All returns are computed over the period January 1974 to September 1997. We use the log-first differences of value-weighted indices and the log-first difference of the exchange rates.

Table 1 provides summary statistics. In order to save space we report only the January 1974 to September 1987 and November 1987 to September 1997 sub-period results. This partition is motivated by the October 1987 stock market crash. Table 1 shows that the average return for each equity market is positive and significantly different from zero in the first sub-period. On average, the Canadian dollar experiences a weekly depreciation of about 0.04% against the dollar, while the Japanese yen has an average weekly appreciation of about 0.104%, both at less than the 10% level of significance. The pound gains an average of 0.045% weekly against the dollar but is not significant at conventional levels. In the second sub-period, only the Japanese equity market has an average return that is significant at the 5% level. Consistent with earlier studies (see, eg, Bekaert and Hodrick (1992)), equity returns are generally more volatile than exchange rate changes. An important implication of these findings is that we may only find unidirectional causality from the more volatile equity markets to the currency markets.

In the first sub-period all stock returns series, except for the U.K., are free of significant autocorrelation at the 5% level of significance. In the second sub-period both the Japanese and the U.K. equity returns display significant autocorrelation up to the fourth lag (p-value = 0.026) and the eighth lag (p-value = 0.000), respectively. Generally, all the exchange rates have significant autocorrelation indicating lags in the time taken to impound relevant information. This is surprising given the relatively large size and substantial liquidity of the currency market. The squared returns display autocorrelations that are characteristically larger and more persistent (generally up to the eighth lag) than the autocorrelations in the returns. The p-values are generally less than 0.05, suggesting that there are ARCH errors in all the series. This supports the choice of a GARCH framework for our estimation. The Jarque-Bera test for normality indicates that the returns are not normally distributed, as they all have excess kurtosis and most are skewed. Our methodology is robust to both the autocorrelation and non-normality observed in the series.

Table 2 presents cross-correlation results. Several previous studies (eg, Karolyi (1995) for Canada and the U.S., Engle and Susmel (1994) for the U.K. and the U.S.) have reported cross-correlation between the equity returns of the major markets and thus we do not repeat them here. Instead we focus on the relationship between currency and equity returns. Panel A reports the cross-correlation between the U.S. equity returns, the changes in the exchange rates, and the cross-correlation between the squared U.S. return and the squared currency changes. First, as indicated by the bold p-values (p(–2 to 2)), at the 10% level of significance there are eight out of twelve cases where the U.S. equity and the major currency markets have significant correlation over the two sub-periods. Second, judging from the size of the coefficients on the contemporaneous unconditional correlation relative to the lead coefficients (lag = –1, –2) or the lag coefficients (lag = 1, 2), most of this correlation between the U.S. equity and the major currency markets take place in the current period. However, the U.S. equity market leads the yen, p(–2 to –1) = 0.036 and the pound p(–2 to –1) = 0.052, and lags the squared pound p(1 to 2) = 0.055 in the first sub-period. The existence of these lead/lag relationships, albeit unconditional, between the currency and equity markets suggests the possibility of conditional cross-market dependence in both the mean and volatility.

Panel B reports similar relationships between one of the other equity markets and its exchange rate with the U.S. dollar. Consistent with our earlier findings, in several cases there is a significant contemporaneous correlation between equity returns and currency changes. In addition, the Japanese the equity returns lead the yen exchange rate changes while the squared U.K. equity returns lead the squared pound exchange rate changes. In no case does the currency market lead the associated stock market.

In summary, from the foregoing unconditional correlation analyses we can conclude that there is a significant, primarily contemporaneous, relationship between the major equity and foreign exchange markets. This supports the finding of De Santis and Gerard (1998) and Dumas and Solnik (1995), among others, that currency risk is a priced factor in the equity markets. The results also indicate that there is a tendency for the equity market to lead the currency market, but not vice versa. This suggests that we may not find significant cross-correlations between the currency and the equity markets. However, this conclusion would be a bit premature because the correlations analyzed above are unconditional correlations. As shown by De Santis and Gerard, results obtained from unconditional models can be dramatically different from those obtained from conditional models where conditional cross-correlations are used instead of unconditional correlations. This is the case because the correlations are conditioned on information available to investors.

The issue of conditional cross-correlation is addressed below where we obtain correlations conditioned on past returns and past shocks to both equity returns and changes in foreign exchange rates. The finding that the U.S. equity market leads the yen and the (squared) pound could be reflecting the earlier findings that the U.S. equity market leads the Japanese and U.K. equity markets (see, eg, Lin, Engle, and Ito (1994) and Connolly and Wang (2000)) while the Japanese and U.K. equity returns are contemporaneously correlated with their corresponding currency returns. This suggests that any documented relationship between the U.S. equity market and these currencies without filtering out the effects of the latter's home equity markets will give a biased picture of the true relationship between the U.S. equity returns and the foreign currencies. In the estimation below, we filter out the effects of the home equity returns on the currencies so that the currencies' impact on the U.S. equity returns can be independently assessed.

4 Empirical results

The empirical results of the paper are presented in this section. First, over the full period we investigate the existence of short-run dependence between currency and equity markets using pairs of equity markets and the exchange rate between these markets. Specifically, we study the U.S., Japan, and the yen; the U.S., Canada, and the Canadian dollar; and the U.S., U.K., and the pound. Next, we focus on two sub-periods, 1974 to September 1987 and November 1987 to September 1997. The relevance of this is that several authors have attributed the existence of cross-autocorrelation between international markets to market segmentation that we expect will decline over time. For instance, Karolyi (1995) finds that the level of the dependency between the U.S. and Canada declines in the more recent period of his study. On the other hand, some researchers (eg, Roll (1989) and others) point out that with increasing volatility there is the tendency for *contemporaneous* lagged transmissions to increase. Given the effect of the 1987 stock market crash and the greater propensity of markets to move together since then, we may find an increase in the dependency between currency and equity markets.

The third set of reported results explores the impact of increased exchange rate volatility on the correlation between each pair of equity markets. If higher volatility in the currency markets lead to increased co-movements between equity markets, then not only does this provide support for the pricing of currency risk in equity returns, but it also suggests that equity market contagion can originate in non-equity markets. Recent examples of this are the Mexican peso crash of December 1994 and the Asian crisis of 1997. Finally, to shed further light on this issue, we examine the effect of foreign exchange liberalization in Japan in December 1980 on the correlation between the U.S. and Japanese equity markets by comparing the 1977 to 1980 period to the post-liberalization period January 1981 to December 1984. This period is not affected by the heightened volatility following the 1987 stock market crash and is considered a period during which these equity markets are segmented, hence, the impact of highly integrated markets on the results is reduced.

4.1 Full-period results

Table 3 reports the results of the tests between the U.S. and Japanese equity markets and the yen/dollar exchange rate. The results provide no evidence of dependence in the mean between the equity and currency markets. The lack of a significant mean cross-autocorrelation between currency and equity markets is consistent with evidence provided by most studies that find lack of mean dependence between major *currency* markets (see, eg, Engle, Ito, and Lin (1990) and Engle and Susmel (1994)). However, consistent with several previous results, the four-week lag of the Japanese equity returns marginally impacts on the current mean of the U.S. equity market (coefficient = –0.056, t = –1.92), and the mean of the U.S. equity market leads the Japanese market by one week (coefficient = 0.064, t = 2.27).

In the conditional variance equations there is bi-directional predictability between equity and currency markets. For instance, lagged volatility of the yen/dollar rate predicts the volatility of the U.S. equity market (coefficient = 0.228, t = 1.82), but not the volatility of the Japanese equity market. On the other hand, the variance of the yen is predicted by past volatility of U.S. (coefficient = 0.110, t = 2.61) and Japanese stocks (coefficient = 0.038, t = 5.96). The volatility of the yen is also predicted by past shocks to the U.S. stocks (coefficient = 0.021, t = 1.88). We also find that U.S. equity volatility depends on past volatility of Japanese stocks (coefficient = 0.480, t = 4.06), but not vice versa.

The strong evidence of bi-directional causality in volatility between equity and currency markets is important on several accounts. First, it suggests that the general lack of evidence of exchange rates having an impact on equity markets reported by the extant literature (see, eg, Jorion (1991) and Griffin and Stulz (2001)) is probably due to the fact that they focus on the first moment and not on the second. Second, finding a relationship between currency and equity markets through their conditional second moments is consistent with the De Santis and Gerard (1998) results that exchange rate is a priced factor in conditional asset pricing models. Third, to the extent that order flow impacts international equity markets the causality in volatility between currency and equity markets is consistent with the conjecture that order flow influences exchange rates not only through its mean, as reported by Evans and Lyons (2001), but also through its conditional second moments (see more below). Finally, the currency/equity feedback is important because it has implications for U.S. trading in Japanese equity derivatives, and vice versa, as the value of these securities are impacted more by volatility than by the mean of the yen/dollar exchange rate.

Table 4 reports results for the U.S., U.K., equity markets and the pound/dollar exchange rate. Similar to the Japanese case, there is an absence of mean causality between currency and equity returns. However, we find significant bi-directional causality between the U.S. and U.K. stock markets. Consistent with several previous results (Hamao et al. (1990), King and Wadhwani (1990)), the magnitude of the impact of the U.S. market on the U.K. market is substantially larger (about twice the size) and more persistent than that of the U.K. on the U.S.

The results of conditional volatility tests are consistent with those for the Japanese markets where the significant relationship between the currency and equity markets is between the second moments and not the first. The current volatility of both the U.S. and U.K. stock markets is significantly impacted by the lagged conditional variance of the pound/dollar exchange rate. The predictive ability of the past volatility of both equity markets for the current volatility of the exchange rate is also significant. Additionally, our results indicate evidence of volatility feedback between U.S. and U.K. equity markets. These findings are inconsistent with those of Engle and Susmel (1994) who find no significant mean or volatility spillovers between U.K. and U.S. equities. A possible explanation for differences in results is that we use a multivariate GARCH approach that includes exchange rate, thus increasing the amount of information that is used in the variance-covariance matrix relative to their univariate model.

In results from both the U.K. and the Japanese markets an interesting and important pattern is observed in the size of the lagged variance coefficient of the foreign currency in the conditional variance of the foreign stocks relative to the lagged variance of the pound in the conditional variance of the U.S. stocks. Intuitively, one might expect that the pound and U.K. stocks would have a stronger relationship, as exemplified by the size of the coefficients. On the contrary, lagged volatility of the pound predicts the U.S. equity volatility with coefficient = 0.196 (t = 4.20), while it predicts the U.K. volatility with coefficient = 0.095 (t = 4.22). Similarly, U.S. equity volatility has greater predictive power for the pound volatility than does the U.K. equity volatility for the pound (0.116 (t = 3.46) vs. 0.028 (t = 5.28)). Additionally, only in the case of the U.S. market do past shocks predict, albeit marginally, the current volatility of the pound.

The pattern in the results for the U.S. and Japanese equity returns and the yen reported in Table 3 are similar to those observed for the U.S. and U.K. stock markets and the pound. The apparently counter-intuitive results, support and extends to the second moments the order-flow exchange rate determination argument of Evans and Lyons (2001). That is, changes in exchange rates do impact local equities, but in these industrialized economies where significant blocks of funds flow freely across borders, exchange rate fluctuations have an even greater impact on order flow to foreign equity markets. The changes in equity order flow in turn perturb the currency order flow (observed by Evans and Lyons (2001)) and lead to exchange rate changes. Thus, pound (yen) volatility and the U.S. equity volatility are more highly cross-correlated than the pound (yen) and U.K. (Japanese) stocks.

Finally, when foreign currency predicts volatility of the U.S. market the coefficient is about twice that of the case where the U.S. market predicts currency volatility. Except in the case of Japan, where past yen volatility does not predict the current variance of the Japanese market, there is also the same pattern in the relationship between variances of the foreign equity market and foreign currency. Thus our results indicate that currency volatility has a much more significant impact on equity volatility than equities have on currency markets. Again, this finding is important given the preponderance of the lack of evidence that currency markets impact equity markets at the aggregate level (eg, Griffin and Stulz (2001)).

Table 5 reports results for U.S. and Canadian stock markets and the Canadian dollar/U.S. dollar exchange rate. In the conditional mean equations there is evidence of more significant cross-autocorrelation than in the previous cases. The first three lags of both the U.S. and Canadian equity returns predict the current mean of the Canadian dollar. The absolute magnitudes of the coefficients are similar, indicating that both equity markets have similar size impacts on the currency market. However, the cumulative effect of the U.S. market is that past increases in the mean of U.S. equities lead a decline in the mean of the Canadian dollar/U.S. dollar exchange rate (ie, an *appreciation* of the Canadian dollar).

The strong relationship between the U.S. and the Canadian financial markets is probably due to the relatively close relationship between these two equity markets. U.S. investors readily invest in the Canadian market either through direct cross-border transactions or by way of direct listing of Canadian stocks on the U.S. exchanges. This is reflected in the fact that of the major industrialized countries that have stocks listed in the U.S. Canada has the largest percent (45%) of their market capitalization listed in the U.S. (Ahearne, Griever, and Warnock (2000)). An implication of this substantial cross-listing is that if the U.S. stock market experiences robust growth U.S. investors know that this will in general spill over to the Canadian market. In light of this, and subsequent to the start of the U.S. boom, U.S. investors turn their attention to the Canadian market. In the process the demand for Canadian dollars increases causing an appreciation in the Canadian currency relative to the U.S. dollar.

On the other hand, the results also indicate that when the Canadian equity market experiences an increase in returns, the Canadian dollar experiences depreciation against the U.S. dollar over the next three weeks. A possible explanation of these results is that when the Canadian equity market picks up (subsequent to the U.S.), the U.S. market would already be experiencing high growth with perhaps a promise of greater returns than Canada.[7] This induces the Canadian investors to increase their holdings in the U.S. market. The result is an increase in the demand for the U.S. dollar causing a depreciation of the Canadian dollar.

We also find that an increase in the mean of the Canadian dollar/U.S dollar rate (depreciation of the Canadian dollar) leads to a significant decline in the returns on the Canadian stocks (coefficient = –0.165) in the following week. By the third week the decline in the stock market is reversed (coefficient = 0.100). If the Canadian dollar loses value relative to the U.S. dollar, then foreign (U.S.) investors withdraw their investments in Canadian stocks causing a decline in the stock prices. With a large enough adjustment to Canadian stock prices, returns subsequently (in week three) become positive.

There is also significant and persistent bi-directional causality between the Canadian and U.S. stock markets. These are inconsistent with financially integrated markets and are similar to the results of Karolyi (1995). Several other studies (eg, Jorion and Schwartz (1986) and Mittoo (1992)) using different methodologies than the one used in this paper also provide evidence that the U.S. and Canadian stock markets are segmented. Since Karolyi shows that the degree of segmentation has declined over time, we address this issue below.

In the conditional volatility equations we observe a similar but less consistent pattern than those present in the previous markets. First, there is significant dependence between the currency and equity markets. The lagged variance of the currency market has approximately the same impact on the current volatility of both the U.S. (coefficient = 0.62, t = 2.5) and the Canadian (coefficient = 0.547, t = 2.19) equity markets. The U.S. equity market's impact on the currency volatility is small (0.030) and insignificant. However, the Canadian equity market's lagged volatility impact on the currency volatility is twice the size and statistically significant (coefficient = 0.06, t = 2.18).

As is shown by these coefficients, for the case of Canada the impact of the currency volatility on both equity markets is about 10 times stronger than the impact of the equity volatility on the currency market. We conjecture that this has to do with the perceived weakness of the Canadian dollar against the U.S. dollar over the sample period of this paper and the tendency for investors to switch investments between the Canadian and U.S. markets in periods of weakness of the

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[7] Perhaps, the historical underperformance of the Canadian economy relative to the U.S. fosters this response.

Canadian currency. Similar to previous results, the impact of the currency volatility on the U.S. market is (slightly) greater than its impact on the Canadian equity market. Unlike in the cases of Japan and the U.K., however, the Canadian equity volatility has a larger impact on the current volatility of the Canadian dollar than does the U.S. equity volatility on the Canadian dollar.

Model diagnostics reported in Panel C of Tables 3 to 5 suggest that the GARCH model is well specified. Therefore we can conclude that these results are not an artifact of model misspecification. The Ljung-Box chi-square test indicates that the model removes all the raw and practically all squared autocorrelation, even if it fails to remove most of the skewness and excess kurtosis from the series. The QML estimation procedure corrects for the non-normal distribution of the standardized errors.

4.2 Increasing impact of exchange rate volatility on equity volatility

Currency volatility has increased over time as an increasing number of governments adapted relatively freely floating currencies after the failure of the Bretton Woods system of fixed exchange rates in 1973.[8] Consequently, it is expected that there will be a greater impact of lagged currency volatility on the current volatility of equity markets. This should be accompanied by declining cross-correlation between equity markets as they become more integrated with each other.

In light of the above, we conduct sub-period tests, the results of which are in Tables 6 to 8. First, in the mean equations we find mixed support for the proposition that as time passes there is a decline in the causality between equity markets, due to increasing integration. There is a slight increase in the ability of past mean of U.S. stocks to predict the current mean of Japanese stocks (coefficients = 0.09 and 0.095 in the two sub-periods, respectively). The predictive ability of the lagged mean of Japan to predict the current mean of the U.S. increases over the two sub-periods (coefficients = 0.093 for the fourth lag and 0.146 for the second lag, respectively, in the sub-periods). However, the U.S. responds quicker (after two weeks) to changes in the Japanese returns in the second period.

Turning to the U. K. system of equations there is no evidence of significant causality in the mean of the U.K. and U.S. equity markets in the second period, consistent with the notion that these two markets have become highly integrated

[8] For anecdotal evidence of increasing currency volatility one can look at the withdrawal of the U.K. from the Exchange Rate Mechanism (ERM) in 1992 (see, eg Bollerslev (1990)), the Mexican pseo crash of December 1994, and the Asian currency crisis of 1997.

with each other. On the other hand, we find small but significant mean causality from the U.S. to Canada in the second period and marginal predictability in the reverse direction. This is surprising since we do not find any significant predictability in the first period and Jorion and Schwartz (1986) and Mittoo (1992), both directly testing if Canada is integrated with the U.S., point to the tendency for Canada to become more integrated with the U.S. over time. It should be noted that Karolyi (1995) also finds similar results in his investigation of mean spillovers between the Canadian and U.S. equity markets.

In relation to mean causality between currency and equity markets, we find no qualitative difference for the yen and the pound in the sub-period results when compared to the full period. In the Canadian market the lagged transmissions from U.S. and Canadian equity markets to the currency market are less persistent in the sub-period results. They have the same signs and approximately equal sizes across sub-periods, but are less persistent in the second period than in the first.

In the conditional volatility equations, the patterns that emerge in the full period also appear in the sub-period analyses. For example, the past volatility of the yen has a greater predictive ability on the volatility of the U.S. equity market than in the volatility of the Japanese equity market. This also holds for the lagged variance of the Canadian dollar in the first sub-period and for the past shock of the Canadian dollar in both periods. For the pound, the impact on the U.K. equity market is greater than that on the U.S. market in the second period and insignificant in the first. The results also indicate that similar to the results from the mean equations, the bi-directional causality in volatility between U.S. and Canadian equity markets occur in the second sub-period. This is surprising given that prior evidence indicates that financial markets are becoming more integrated. A possible explanation for our results is that the relationship is due to the increased amount of equity order flow between the countries that has occurred overtime (see, eg, Froot, O'Conell, and Seasholes, (2000)).

What is clear from the sub-period results is that, across sub-periods, there is a significant increase in the impact of lagged currency market volatility on equity markets volatility. This is true in all cases except for the lagged variance of the Canadian dollar on the current volatility of the U.S. equity market, even though the relationship remains economically and statistically significant (coefficients = 1.017 and 0.510, respectively, in Table 8). However, the ability of the past shocks (lagged squared errors) of the Canadian dollar to predict the current volatility of the U.S. equity market doubles in the second subperiod (coefficients = 0.226 and 0.445, respectively in Table 8). Since the "shock" is a measure of the extent that the realized value of the Canadian dollar/U.S. dollar exchange rate wanders from its near-term expected value, the increase in the second period of the impact of shocks on the U.S. equity market indicate an overreaction on the part of the latter to changes in the currency market, supporting the argument about increased order flow. Furthermore, in cases where equity market volatility predicts foreign exchange rate volatility, there is generally a decrease in the impact moving from the first sub-period to the second. For example in Table 8, the impact of the U.S. (Canadian) equity market on Canadian dollar volatility declines from 0.077, t = 5.27 (0.115, t = 6.58) in the first period to 0.030, t = 2.46 (0.086, t = 5.10) in the second period.

These findings are consistent with the argument that the further we move away from fixed to floating exchange rate systems and as exchange rate policy becomes a more important part of monetary policy causing more government intervention in the currency markets, the greater the potential for currency volatility to affect the real economy and with it the capital markets. The close union between Canada and the U.S. increases this potential. As a result we observe greater cross-autocorrelation between them especially from the U.S. to Canada.

4.3 The relationship between currency volatility and correlation between equity markets

Results thus far indicate that currency volatility is an important determinant of equity market volatility in subsequent periods. It suggests that high currency volatility has the potential to increase equity market volatility, which in turn, could lead to contagion of other equity markets. We therefore investigate if in periods when currency volatility is greater than its long-run average if it leads to greater correlation between equity markets.

Panel A of Table 9 reports the results where the correlation between the U.S. and another country's equity returns is conditioned on the volatility of the corresponding exchange rate. Because the results from the conditional mean model is not significantly different from those previously reported and given the main objective of this section we report only the conditional variances and the correlation between the equity markets. The full model, including various diagnostic tests on the residuals of each equity market and the cross product of these residuals, is available on request. All nine conditional variance models in either period are well specified, with the ARCH and GARCH coefficients (a and b in the table) having the expected relative size relationship found in these models. Coefficients under the correlation column, r_0, are the unconditional contemporaneous correlation between the equity markets, between the foreign equity market and the currency, and between the U.S. equity market and the currency, respectively. For instance, in the first period the unconditional correlation between the U.S. and Japanese equity markets is 0.270, between the Japanese equity and currency markets is –0.139, and between the U.S. equity and the yen it is -0.114. Correlations between equity and currency markets are directly comparable to the correlations at lag = 0 in Table 2. All coefficients in Panel A have the expected signs and in general are similar in magnitude to those in Table 2, supporting the accuracy of the estimated GARCH model.

A closer inspection of the sub-period results show that in the first sub-period, 1974 to September 1987, the correlation between the U.S. and Japanese equity markets increased by 0.075 (t = 13.3) as a result of greater-than-average volatility of the yen. We return to this result below. The U.S./U.K. correlation also increased but the result is not significant at conventional levels. Interestingly, and in the spirit of previous results, the U.S./Canada correlation declined but this is also not significant. In the second sub-period both Japanese and U.K. equity markets experience closer correlation with the U.S. market, but these increases are not significant at conventional levels. On the other hand, an increase in Canadian dollar volatility caused a decline of 0.062 in the correlation between the equity returns of the U.S. and Canada. This finding is in all likelihood related to the quadrupling of the impact of the lagged volatility of the Canadian dollar on the Canadian equity volatility from period one to period two (Table 8) and to the increased order flow between Canada and the U.S. ((eg, Froot, O'Conell, and Seasholes, (2000)). It also suggests that as the Canadian dollar volatility increases, U.S. investors withdraw from the Canadian market causing a decline in the correlation between the two markets.

4.4 Currency liberalization and correlation across equity markets

In support of the finding that in the first sub-period increased currency volatility leads to an increase in the correlation between the U.S. and Japanese markets we investigate the impact of foreign exchange liberalization in the Japanese economy in December 1980 (see, eg, Gultekin, Gultekin, and Penati (1989)). Specifically, we test the null hypothesis that given the removal of foreign exchange restrictions and the likely subsequent increase in currency volatility, the conditional correlation between the U.S. and Japanese equity markets increased in this sub-period. We estimate the conditional correlation GARCH model over the period January 1977 to December 1984 and condition the correlation between the equity markets first on a dummy variable that takes the value one in the post-liberalization period and zero otherwise (FXLIB). Next we condition on an interaction variable FXLIB*FXVOL, to determine if increased volatility following the liberalization of the currency market leads to greater correlation between the equity markets.

Panel B of Table 9 reports the results. On the left hand side, we find that there is an economically significant increase of 0.147 in the correlation between the

U.S. and Japanese stock markets after the liberalization of the Japanese currency market. However, this is not statistically significant. From the right side of Panel B, we see that the correlation between the equity markets increased (marginally) in the post-liberalization period as a result of higher-than-usual yen volatility (coefficient = 0.029, t = 1.82), though the economic impact is marginal.

5 Summary and conclusions

This paper investigates the dynamic relations between the major currency and equity markets. Specifically, we test for bi-directional causality between the mean and volatility of the Canadian dollar, the British pound, and the Japanese yen and the mean and volatility of the U.S. stock market paired with each of the Canadian, U.K., and Japanese equity markets, respectively. Additionally, we examine whether or not higher-than-usual volatility in the currency markets influences the relationship between equity markets.

The main results are that past volatility of currency markets has significant predictive power for the current volatility of equity securities and that greater-than-average currency volatility leads to increase correlation between equity markets. Further, although the equity markets also predict the volatility of currency markets, this relationship is much weaker than the reverse, especially in the period after 1987. Additionally, except for the case of Canada there is hardly any significant mean predictability between equity and currency markets. Finally, we find that the usual cross-correlation between the U.S. and major equity markets is robust to filtering for the exchange rate effect. These cross-correlations declined in the period after 1987, except in the case of Canada where it is significant only in this sub-period.

What is clear from these results is that the relationship between currency and equity markets is bi-directional, significant, persistent, and independent of the relationship strictly between equity markets. Furthermore, this relationship is better captured in the conditional second moments. There are two broad implications of these results. First, researchers in the area of (international) asset pricing have up to this point underestimated the impact of currency markets on equities because they have focused on the impact of currency markets on the mean of equity returns. Second, macroeconomists have failed to fully understand the determinants of exchange rate as up to now there is hardly any role for the dynamics of the equity market in their models.

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Tables 1–9

Table 1. **Summary statistics for weekly returns on equity indices and exchange rates**

	January 1974 to September 1987 (694 obs)											
	Mean	p: Mean	Std Dev.	SK	XKU	p: J-B	Auto(L)	p: LB(4)	p: LB(8)	Auto(S)	p: LB(4)	p: LB(8)
US	0.170	0.042	2.194	0.108	1.697*	0.000	–0.016 0.016	0.612	0.314	0.045 0.110*	0.000	0.000
CN	0.168	0.030	2.037	0.224*	1.865*	0.000	0.097* 0.015	0.075	0.193	0.087* 0.092*	0.000	0.000
JP	0.303	0.000	1.794	–0.057	2.099*	0.000	0.024 0.059	0.167	0.394	0.137* 0.119*	0.000	0.000
UK	0.314	0.002	2.711	0.976*	8.407*	0.000	0.128* 0.124*	0.000	0.000	0.107* 0.285*	0.000	0.000
C$	0.040	0.063	0.567	0.783*	7.391*	0.000	0.110* 0.022	0.047	0.052	0.103* 0.047	0.016	0.126
Yen	–0.104	0.052	1.404	–0.639*	2.103*	0.000	0.120* 0.131*	0.000	0.002	0.243* 0.067	0.000	0.000
Pd	–0.045	0.398	1.412	0.182	2.302*	0.000	0.054 –0.014	0.146	0.050	0.133* 0.101*	0.000	0.000

	November 1987 to September 1997 (503 obs)											
	Mean	p: Mean	Std Dev.	SK	XKU	p: J-B	Auto(L)	p: LB(4)	p: LB(8)	Auto(S)	p: LB(4)	p: LB(8)
US	0.105	0.292	2.241	0.221*	1.888*	0.000	0.004 –0.013	0.617	0.318	0.032 0.106*	0.000	0.000
CN	0.149	0.122	2.151	0.258*	1.857*	0.000	0.102* 0.005	0.116	0.223	0.062 0.077	0.023	0.000
JP	0.194	0.004	1.524	–0.169	2.006*	0.000	0.001 0.035	0.026	0.070	0.059 0.045	0.000	0.000
UK	0.239	0.072	2.972	1.083*	7.866*	0.000	0.135* 0.120*	0.000	0.001	0.100* 0.279*	0.000	0.000
C$	0.045	0.062	0.543	0.809*	6.611*	0.000	0.147* 0.075	0.004	0.006	0.127* 0.057	0.039	0.236
Yen	–0.051	0.416	1.395	–0.513*	1.768*	0.000	0.082* 0.123*	0.018	0.077	0.251* 0.137*	0.000	0.000
Pd	–0.088	0.117	1.263	–0.259*	1.838*	0.000	0.036 –0.019	0.084	0.154	0.146* 0.072	0.005	0.000

* Significant at the 0.05 level. SD is standard deviation, SK is skewness, and XKU is excess kurtosis. p: J-B is the p-value of the Jarque-Bera test of normality. Auto(L) are the autocorrelation coefficients of the returns on the respective series, at the first (top) and second (below) lags. p:LB(x) are p-values of the Ljung-Box test of significance of autocorrelation at x lags. Similarly, Auto(S) are the autocorrelation of the squared returns.

Table 2. **Cross-correlation between currency and equity markets**

	January 1974 to September 1987 (694 obs)						November 1987 to September 1997 (503 obs)					
	US equity returns			US squared equity returns			US equity returns			US squared equity returns		
	C$	Yen	Pd	SqC$	SqYn	SqPd	C$	Yen	Pd	SqC$	SqYn	SqPd
Lag=–2	–0.056	–0.024	0.010	–0.032	0,053	–0,049	–0,031	–0,046	–0,008	–0,038	0,073	–0,005
Lag=–1	–0.039	–0.070	0.069	–0.044	0,030	0,005	–0,034	–0,064	0,064	–0,036	0,033	0,020
Lag=0	–0.135	–0.100	0.054	0.009	0,065	–0,026	–0,154	–0,116	0,094	0,038	0,103	0,034
Lag=1	0.020	–0.013	0.006	–0.003	0,026	–0,019	0,015	0,005	0,000	–0,004	0,035	0,019
Lag=2	–0.008	0.053	0.022	–0.027	0,032	–0,067	–0,020	0,046	0,049	–0,034	0,026	–0,052
p(–2 to –1)	0.199	**0.036**	**0.052**	0.348	0.107	0.234	0.586	0.205	0.353	0.500	0.197	0.902
p(1 to 2)	0.854	0.165	0.736	0.771	0.350	**0.055**	0.851	0.588	0.547	0.746	0.624	0.455
p(–2 to 2)	**0.006**	**0.000**	**0.075**	0.747	**0.040**	**0.090**	**0.020**	**0.050**	0.172	0.743	**0.089**	0.795

	JP equity returns:		UK returns:		CN returns:		Japan returns:		UK returns:		CN returns:	
	Level	Squared	Level	Squared	Level	Squared	Level	Squared	Level	Squared	Level	Squared
	Yen	SqYn	Pd	SqPd	CS	SqC$	Yen	SqYn	Pd	SqPd	C$	SqC$
Lag=–2	–0.077	0.003	–0.02	–0.048	–0.011	0.004	–0.049	0.024	–0.002	–0.038	0.009	0.019
Lag=–1	–0.060	–0.022	0.004	–0.053	–0.023	–0.011	–0.041	–0.049	0.012	–0.053	–0.026	0.001
Lag=0	–0.177	0.032	0.113	–0.040	–0.247	0.071	–0.181	0.094	0.125	–0.031	–0.278	0.097
Lag=1	–0.042	–0.041	0.004	–0.039	–0.056	0.045	–0.019	–0.054	0.026	–0.025	–0.070	0.055
Lag=2	0.011	0.010	0.014	–0.019	–0.031	–0.009	0.042	–0.003	0.007	–0.001	–0.004	–0.006
p(–2 to –1)	**0.003**	0.752	0.781	**0.047**	0.806	0.953	0.349	0.464	0.960	0.342	0.826	0.908
p(1 to 2)	0.322	0.335	0.882	0.316	0.242	0.477	0.579	0.470	0.832	0.852	0.283	0.465
p(–2 to 2)	**0.000**	0.555	**0.006**	**0.067**	**0.000**	0.404	**0.001**	0.186	0.136	0.708	**0.000**	0.263

SqX is the squared change in the exchange rate series X. The change and squared change of each exchange rate is cross-correlated with the returns and squared returns, respectively, on the equity series above it. p(–x to x) is the p-value from the Ljung-Box test of significance of the cross-correlation between the equity series at the top of the column and the currency series below, from lag –x (lead of the equity series) to lag x. Cross-correlations significant at up to the 10% level are in bold.

Table 3. **Cross-correlation between the US, Japan, and Yen/$ exchange rate**

Panel A: Cross-correlation in Mean

	Lag	US Returns Coeff.	US Returns t-value	Japan returns Coeff.	Japan returns t-value	Yen/$ changes Coeff.	Yen/$ changes t-value
US returns	1	–0.052	–2.161	0.064	**2.266**	–0.015	–0.879
	2	0.028	1.217	–0.025	–0.864	0.019	1.111
	3	0.044	1.702	0.028	0.939	0.022	1.147
	4	–0.010	–0.409	0.024	0.791	–0.001	–0.060
Japan returns	1	0.004	0.163	–0.001	–0.014	–0.014	–0.845
	2	0.038	1.397	0.051	1.434	–0.026	–1.333
	3	–0.016	–0.690	0.053	1.537	0.000	0.009
	4	–0.056	**–1.923**	–0.019	–0.641	–0.002	–0.075
Yen/$ changes	1	–0.025	–0.497	0.007	0.158	0.059	1.775
	2	0.049	1.004	0.042	1.267	0.078	2.795
	3	–0.049	–0.816	–0.036	–0.846	0.044	1.749
	4	–0.016	–0.324	0.003	0.108	0.009	0.437
	Const.	0.229	3.360	0.191	3.702	–0.073	–1.358

Panel B: Cross-correlation in variance

	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
Lagged conditional variance						
US volatility	0.958	53.21	0.070	1.228	0.110	**2.611**
Japan volatility	0.480	**4.064**	0.968	37.95	0.038	**5.964**
Yen/$ volatility	0.228	**1.817**	0.019	1.268	0.966	63.39
Lagged squared errors						
US shock	0.224	4.697	0.000	0.013	0.021	**1.877**
Japan shock	0.038	1.286	0.296	5.585	0.023	1.195
Yen/$ shock	0.025	0.503	0.019	0.706	0.204	6.379

Panel C: Standardized residual diagnostics

		US return		Japan returns		Yen/$ changes	
Skewness	(p-value)	–1.108	0.000	–0.368	0.000	–0.640	0.000
Kurtosis	(p-value)	11.54	0.000	2.738	0.000	2.567	0.000
Jarque-Bera	(p-value)	6884.7	0.000	400.5	0.000	409.8	0.000
Autocorrelation	(level)						
LB(6)	(p-value)	10.57	0.103	2.665	0.850	3.165	0.788
LB(12)	(p-value)	18.61	0.098	8.813	0.925	10.74	0.552
Autocorrelation	(squared)						
LB(6)	(p-value)	0.399	0.999	8.172	0.226	13.90	0.031
LB(12)	(p-value)	0.919	0.999	13.20	0.355	14.99	0.242
Loglikelihood		–3783.723					

Robust Wald tests of parameter restrictions

Zero restrictions on Block of Lags in the conditional mean equations

(1)$\chi^2(36)$ = 61.854, p-value = 0.005

Zero restrictions on coefficients in the conditional variance equations

(2)$\chi^2(6)$ = 78699.481, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. Alll residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 4. **Cross-correlation between the US, U.K., and Pound/$ exchange rate**

Panel A: Cross-correlation in Mean
(Jan. 1974 to Sept. 1997 (T=1203))

	Lag	US Returns Coeff.	US Returns t-value	UK returns Coeff.	UK returns t-value	Pound/$ changes Coeff.	Pound/$ changes t-value
US returns	1	–0.057	–2.229	0.084	**3.230**	0.020	1.102
	2	–0.002	–0.103	0.013	0.510	–0.004	–0.201
	3	0.016	0.642	0.050	1.825	0.001	0.078
UK returns	1	0.037	1.550	0.025	0.786	–0.007	–0.461
	2	0.040	**2.618**	0.070	4.256	–0.009	–0.614
	3	–0.024	–1.015	–0.042	–1.493	–0.016	–1.218
Pound/$ changes	1	0.044	1.023	–0.059	–1.504	0.027	1.007
	2	0.038	1.040	0.022	0.573	0.018	0.808
	3	0.047	1.034	0.043	1.285	0.060	2.718
	Const.	0.185	3.227	0.211	3.771	–0.018	–0.389

Panel B: Cross-correlation in variance

	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
	Lagged conditional variance					
US volatility	1,073	62,34	0,602	**16.15**	0.116	**3.461**
UK volatility	0,383	**9.823**	1,070	69,98	0.028	**5.278**
Pound/$ volatility	0,196	**4.201**	0,095	**4.219**	0.922	47.53
	Lagged squared errors					
US shock	0.181	2.771	0.123	**6.302**	0.047	**1.946**
UK shock	0.012	0.257	0.271	7.984	0.015	1.197
Pound/$ shock	0.038	1.449	0.061	1.160	0.298	5.449

Panel C: Standardized residual diagnostics

		US return		UK returns		Pound/$ changes	
Skewness	(p-value)	–1.190	0.000	–0.619	0.000	–0.359	0.000
Kurtosis	(p-value)	12.39	0.000	6.519	0.000	2.047	0.000
Jarque-Bera	(p-value)	7732.3	0.000	2194.2	0.000	234.5	0.000
Autocorrelation	(level)						
LB(6)	(p-value)	10.44	0.107	3.569	0.735	5.146	0.525
LB(12)	(p-value)	17.75	0.123	8.892	0.712	10.27	0.593
Autocorrelation	(squared)						
LB(6)	(p-value)	0.923	0.988	1.594	0.953	8.349	0.214
LB(12)	(p-value)	1.753	0.999	1.963	0.999	13.30	0.348
Loglikelihood		–3821.593					

Robust Wald tests of parameter restrictions
Zero restrictions on Block of Lags in the conditional mean equations
(1)$\chi^2(27)$ = 95.059, p-value = 0.000
Zero restrictions on coefficients in the conditional variance equations
(2)$\chi^2(6)$ = 20030.718, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. Alll residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 5. **Cross-correlation between the US, Canada, and C$/$ exchange rate**

Panel A: Cross-correlation in Mean

(Jan. 1974 to Sept. 1997 (T=1203))

		US Returns		Canadian returns		CN$/$ changes	
	Lag	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US returns	1	–0.058	–2.064	0.010	0.388	–0.019	**–2.711**
	2	0.001	0.082	0.026	**1.999**	–0.035	**–5.387**
	3	0.029	1.515	0.066	**3.662**	–0.019	**–2.395**
CN returns	1	0.020	0.604	0.098	3.049	0.019	**2.405**
	2	0.018	0.914	–0.016	–0.951	0.025	**3.363**
	3	–0.083	**–3.539**	–0.045	–2.723	0.016	**2.287**
CN$/$ changes	1	–0.058	–0.684	–0.165	**–2.547**	0.041	1.188
	2	–0.059	–0.665	–0.091	–1.559	0.052	2.186
	3	–0.003	–0.052	0.100	**1.979**	–0.026	–1.458
	Const.	0.241	4.615	0.153	3.764	0.022	1.153

Panel B: Cross-correlation in variance

	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
			Lagged conditional variance			
US volatility	1.053	29.21	0.125	**2.410**	0.033	1.496
CN volatility	0.166	**3.482**	0.807	16.14	0.060	**2.182**
CN$/$ volatility	0.620	**2.496**	0.547	**2.193**	0.839	25.78
			Lagged squared errors			
US shock	0.100	2.086	0.176	**3.451**	0.017	1.514
Canada shock	0.241	**4.096**	0.445	5.367	0.004	0.264
CN$/$ shock	0.033	0.385	0.080	0.794	0.395	6.554

Panel C: Standardized residual diagnostics

		US return		CN$ returns		CN$/$ changes	
Skewness	(p-value)	–1.040	0.000	–1.077	0.000	0.500	0.000
Kurtosis	(p-value)	9.461	0.000	11.68	0.000	2.918	0.000
Jarque-Bera	(p-value)	4676	0.000	7029	0.000	474.4	0.000
Autocorrelation	(level)						
LB(6)	(p-value)	9.158	0.165	2.422	0.877	5.648	0.464
LB(12)	(p-value)	16.01	0.191	8.989	0.704	12.33	0.419
Autocorrelation	(squared)						
LB(6)	(p-value)	0.897	0.989	0.947	0.988	1.598	0.953
LB(12)	(p-value)	1.459	0.999	1.122	0.999	3.175	0.994
Loglikelihood		–2186.158					

Robust Wald tests of parameter restrictions

Zero restrictions on Block of Lags in the conditional mean equations

(1)$\chi^2(27)$ = 290.924, p-value = 0.000

Zero restrictions on coefficients in the conditional variance equations

(2)$\chi^2(6)$ = 7210.555, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the residuals. Alll residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 6. Sub-period results: US, Japan, and Yen/$ exchange rate

		January 1974 to September 1987 (T=694)						November 1987 to September 1997 (T=496)					
		Panel A: Cross-correlation in mean											
		US returns		Japan returns		Yen/$		US returns		Japan returns		Yen/$	
	Lag	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US	1	–0.023	–0.694	0.090	**2.806**	–0.019	–0.939	0.026	0.543	0.095	**3.514**	–0.031	–1.394
	2	0.030	1.028	–0.014	–0.545	–0.001	–0.067	–0.007	–0.205	0.009	0.369	–0.027	–1.437
	3	0.058	1.672	0.031	1.033	0.014	0.702	0.056	1.509	0.053	**1.982**	–0.003	–0.148
	4	–0.042	–1.581	0.011	0.358	–0.010	–0.446	–0.022	–0.536	0.052	1.606	–0.026	–1.343
JP	1	0.015	0.453	–0.028	–1.017	–0.022	–0.813	0.048	0.679	–0.027	–0.652	–0.017	–0.542
	2	0.063	1.635	0.063	2.091	–0.053	**–2.183**	0.146	**2.922**	0.045	1.102	–0.045	–1.392
	3	–0.051	–1.128	0.051	1.599	0.004	0.166	0.012	0.222	0.094	2.479	0.023	0.804
	4	–0.093	**–2.364**	–0.026	–0.856	0.010	0.372	–0.093	–1.508	–0.042	–1.005	0.007	0.241
Y/$	1	–0.021	–0.323	–0.026	–0.443	0.110	1.944	0.038	0.585	0.009	0.219	0.090	1.914
	2	0.093	1.533	0.048	0.920	0.077	2.215	0.120	1.629	0.068	1.536	0.072	1.664
	3	–0.057	–0.893	0.008	0.144	0.022	0.778	–0.010	–0.149	0.052	1.180	0.050	2.037
	4	–0.088	1.288	–0.031	–0.524	–0.016	–0.658	–0.126	–1.924	–0.035	–0.762	0.007	0.267
	Const.	0.194	2.156	0.252	3.651	–0.057	–0.983	0.032	0.321	0.198	3.160	–0.047	–0.772
		Panel B: Cross-correlation in variance											
		Lagged conditional variance											
		Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US		0.704	13.76	0.236	**4.193**	0.055	1.285	0.548	11.056	0.182	1.778	0.018	0.507
JP		0.936	**10.35**	0.846	24.47	0.034	1.386	0.528	**3.450**	0.587	2.990	0.031	0.372
Y/$		0.278	**2.647**	0.023	**1.789**	0.967	121.1	0.447	**3.041**	0.315	**2.848**	0.948	33.84
		Lagged squared errors											
US		0.287	4.729	0.064	**1.678**	0.017	1.273	0.009	0.091	0.170	**2.664**	0.002	0.077
JP		0.051	0.680	0.199	4.658	0.009	0.703	0.500	**4.111**	0.030	0.399	0.049	**2.154**
Y/$		0.103	1.009	0.051	1.454	0.223	5.757	0.150	1.431	0.012	0.177	0.323	3.883
		Panel C: Standardized residual diagnostics											
		US returns		Japan returns		Yen/$		US returns		Japan returns		Y/$	
Skewness	(p-value)	0.147	0.115	–0.087	0.351	–0.838	0.000	0.046	0.679	–0.154	0.164	–.549	0.000
Kurtosis	(p-value)	0.941	0.000	1.266	0.000	3.002	0.000	0.766	0.001	1.056	0.000	1.893	0.000
Autocorr	(Level)												
LB(6)	(p-value)	3.614	0.729	1.475	0.961	2.789	0.835	3.503	0.744	3.449	0.751	2.477	0.871
LB(12)	(p-value)	8.553	0.741	5.653	0.933	8.702	0.728	7.935	0.790	7.134	0.849	4.733	0.966
Autocorr	(Squared)												
LB(6)	(p-value)	1.790	0.938	6.466	0.373	11.19	0.501	13.14	0.041	6.526	0.367	3.572	0.734
LB(12)	(p-value)	8.965	0.706	17.60	0.128	11.33	0698	25.24	0.014	15.39	0.221	10.24	0.595
Loglikelihood		–1976.977						–1347.703					

Robust Wald tests of parameter restrictions

Zero restrictions on Block of lags in the conditional mean equations

(1)$\chi^2(36)$ = 40.613, p-value = 0.274 (1)$\chi^2(36)$ = 128.942, p-value = 0.000

Zero restrictions on coefficients in the conditional variance equations

(2)$\chi^2(6)$ = 7811.707, p-value = 0.000 (1)$\chi^2(6)$ = 5667.092, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the resicuals. All residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 7. Sub-period results: US, U.K., and Pound/$ exchange rate

		January 1974 to September 1987 (T=694)						November 1987 to September 1997 (T=496)					
		Panel A: Cross-correlation in mean											
		US returns		UK returns		Pound/$		US returns		UK returns		Pound/$	
	Lag	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US	1	–0.026	–0.621	0.096	**2.636**	0.033	1.252	0.001	0.020	0.063	**1.653**	0.048	**1.918**
	2	–0.033	–1.077	–0.020	–0.555	0.003	0.118	–0.037	–1.032	–0.002	–0.047	–0.003	–0.109
UK	1	0.035	1.010	0.051	1.524	0.000	0.019	0.035	1.228	0.055	1.236	–0.018	–0.966
	2	0.094	**3.150**	0.113	3.721	0.004	0.197	0.032	1.180	0.089	**1.916**	0.005	0.270
Pd/$	1	0.009	0.174	–0.028	–0.543	0.043	1.341	0.003	0.035	0.026	0.345	0.017	0.445
	2	0.023	0.415	–0.006	–0.122	–0.025	–0.918	0.086	1.019	–0.060	–0.815	–0.013	–0.294
	Const.	0.146	1.789	0.227	2.993	–0.070	–1.222	0.069	0.676	0.188	1.681	–0.079	–1.325
		Panel B: Cross-correlation in variance											
		Lagged conditional variance											
		Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US		0.759	5.125	0.187	1.386	0.078	1.963	0.979	34.17	0.372	8.172	0.044	0.915
UK		0.236	**2.336**	0.930	74.39	0.095	**1.812**	0.346	**11.79**	0.858	54.07	0.111	**5.511**
Pd/$		0.042	0.498	0.093	0.579	0.944	41.05	0.365	**3.375**	0.649	**5.618**	0.205	2.509
		Lagged squared errors											
US		0.227	2.139	0.097	1.943	0.051	1.161	0.063	1.036	0.329	5.189	0.135	3.539
UK		0.043	0.513	0.358	10.26	0..034	2.287	0.135	4.208	0.459	10.10	0.033	1.386
Pd/$		0.023	0.301	0.037	0.700	0.272	3.765	0.202	1.596	0.109	0.991	0.334	3.481
		Panel C: Standardized residual diagnostics											
		US returns		UK returns		Pound/$		US returns		UK returns		Pound/$	
Skewness	(p-value)	0.082	0.381	–0.008	0.932	–0.035	0.711	0.138	0.210	0.091	0.410	–0.184	0.096
Kurtosis	(p-value)	1.271	0.000	0.578	0.002	1.998	0.000	0.834	0.000	0.734	0.001	1.694	0.000
Autocorr	(Level)												
LB(6)	(p-value)	5.132	0.527	1.017	0.985	12.06	0.061	2.070	0.913	3.904	0.690	13.93	0.030
LB(12)	(p-value)	9.112	0.693	3.731	0.988	21.17	0.048	4.483	0.973	7.736	0.805	29.78	0.003
Autocorr	(Squared)												
LB(6)	(p-value)	13.89	0.031	7.086	0.313	3.509	0.743	4.233	0.645	3.490	0.745	13.80	0.032
LB(12)	(p-value)	24.75	0.016	23.45	0.024	9.398	0.669	8.721	0.727	15.21	0.230	35.43	0.000
Loglikelihood		–2295.949						–1660.668					

Robust Wald tests of parameter restrictions

Zero restrictions on Block of lags in the conditional mean equations

$(1)\chi^2(18)$ = 47.097, p-value = 0.000 $(1)\chi^2(18)$ = 24.385, p-value = 0.143

Zero restrictions on coefficients in the conditional variance equations

$(2)\chi^2(6)$ = 15780.009, p-value = 0.000 $(2)\chi^2(6)$ = 13137.642, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the resicuals. All residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 8. Sub-period results: US, Canada, and C$/$ exchange rate

		January 1974 to September 1987 (T=694)						November 1987 to September 1997 (T=496)					
		Panel A: Cross-correlation in mean											
		US returns		CN returns		C$/$		US returns		CN returns		C$/$	
	Lag	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US	1	0.024	–0.630	0.027	0.736	–0.027	**–3.233**	–0.012	–0.387	0.052	1.421	–0.031	**–3.394**
	2	0.013	0.477	0.031	1.272	–0.032	**–3.715**	–0.043	–1.369	–0.062	**–2.562**	–0.011	–1.012
CN	1	0.004	0.085	0.076	1.650	0.028	**2.467**	–0.040	–1.098	0.033	0.777	0.031	**3.060**
	2	0.025	0.954	–0.022	–0.968	0.025	**2.226**	0.052	**1.735**	0.057	1.353	0.017	1.428
C$/$	1	0.128	1.163	0.051	0.469	0.049	1.629	–0.050	–0.365	–0.167	–1.144	0.106	3.152
	2	0.006	0.057	–0.083	0.088	0.035	1.385	0.067	0.518	0.176	1.569	0.108	3.073
	Const.	0.149	2.321	0.149	2.568	0.030	1.294	0.134	1.821	0.145	2.486	0.030	1.171
		Panel B: Cross-correlation in variance											
		Lagged conditional variance											
		Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value	Coeff.	t-value
US		0.868	23.16	0.007	0.213	0.077	**5.267**	1.136	18.32	0.724	5.204	0.030	2.455
CN		0.051	1.018	0.977	27.96	0.115	**6.580**	0.543	**5.071**	0.754	3.197	0.086	**5.101**
C$/$		1.017	**3.751**	0.672	**2.663**	0.764	17.84	0.510	**1.976**	2.940	**9.565**	0.157	1.545
		Lagged squared errors											
US		0.272	4.523	0.075	1.520	0.032	**1.843**	0.320	4.628	0.021	0.216	0.102	3.625
CN		0.032	0.529	0.250	4.707	0.003	0.139	0.034	0.412	0.252	1.641	0.089	2.654
C$/$		0.226	**1.706**	0.198	1.396	0.542	5.095	0.445	**1.898**	0.253	0.761	0.403	3.106
		Panel C: Standardized residual diagnostics											
		US returns		CN returns		C$/$		US returns		CN returns		C$/$	
Skewness	(p-value)	0.010	0.914	0.072	0.439	0.430	0.000	0.090	0.414	0.240	0.030	0.056	0.610
Kurtosis	(p-value)	0.714	0.000	1.285	0.000	2.987	0.000	0.578	0.009	1.505	0.000	1.222	0.000
Autocorr	(Level)												
LB(6)	(p-value)	2.939	0.817	2.356	0.884	9.294	0.158	2.943	0.816	3.972	0.681	3.682	0.720
LB(12)	(p-value)	6.572	0.885	7.385	0.831	13.19	0.355	6.526	0.887	10.19	0.599	16.34	0.176
Autocorr	(Squared)												
LB(6)	(p-value)	0.974	0.987	3.171	0.787	1.576	0.954	1.882	0.930	7.153	0.307	8.126	0.229
LB(12)	(p-value)	4.010	0.983	15.03	0.240	3.071	0.995	6.022	0.915	27.52	0.007	16.98	0.150
Loglikelihood		–1301.459						–962.613					

Robust Wald tests of parameter restrictions

Zero restrictions on Block of lags in the conditional mean equations

(1)$\chi^2(18)$ = 61.146, p-value = 0.000 (1)$\chi^2(18)$ = 129.633, p-value = 0.000

Zero restrictions on coefficients in the conditional variance equations

(2)$\chi^2(6)$ = 13252.868, p-value = 0.000 (2)$\chi^2(6)$ = 863.323, p-value = 0.000

All t-values are based on quasi-maximum likelihood estimation robust to non-normality in the resicuals. All residual diagnostics are based on standardized residuals. LB(x) is the Ljung-Box chi-squared statistics with associated p-values for testing the null hypothesis of zero autocorrelation up to lag x.

Table 9.

Currency-induced asymmetry in the correlation between equity markets

Panel A:

The following equations are simultaneously estimated. The covariance between the equity markets is augmented by the term FXVOL and that between the equity and currency markets is modeled as a constant.

$R_{i,t} = b_0 + b_1R_{t-1} + b_2R_{t-2} + b_3R_{t-3} + e_{i,t}$; i = U.S. equity market, foreign equity market, and foreign currency market

$h_{i,t} = c + a(e_{i,t-1}e_{i,t-1}) + bh_{i,t-1}$; i = U.S. equity market, foreign equity market, and foreign currency market

$h_{i,j,t} = (r_0 + r_1 FXVOL_{t-1})*(\sqrt{h_{i,t}}\sqrt{h_{j,t}})$; i = U.S. equity market and j = foreign equity market

R is the weekly return on the respective series. FXVOL is an indicator dummy variable taking the value one if the estimated conditional variance of the respective exchange rate is greater than its unconditional (long-run) value and zero otherwise. The unconditional currency volatility is calculated from an estimated equation (not reported) in which the currency-induced asymmetry is omitted.

	January 1974 to September 1987 (T=694)					November 1987 to September 1997 (T=496)				
	Panel A: Conditional variance and covariance equations									
	c	a	b	r_0	r_1	c	a	b	r_0	r_1
US	0.283	0.100	0.842	0.270	**0.075**	0.296	0.124	0.817	0.236	0.027
	(1.748)	(2.557)	(13.79)	(10.23)	**(13.32)**	(3.162)	(2.958)	(17.48)	(5.665)	(1.485)
Japan	0.042	0.066	0.923	–0.139		0.067	0.061	0.909	–0.155	
	(1.827)	(3.451)	(37.51)	(–4.237)		(1.989)	(2.507)	(31.04)	(–3.776)	
Y/$	0.010	0.061	0.937	–0.114		0.018	0.121	0.874	–0.133	
	(0.855)	(2.302)	(32.71)	(–3.391)		(0.932)	(1.872)	(13.25)	(–3.676)	
US	0.279	0.090	0.852	0.340	0.008	0.300	0.111	0.827	0.315	0.021
	(1.525)	(2.537)	(12.38)	(7.602)	(0.321)	(2.385)	(2.487)	(16.38)	(8.852)	(1.066)
UK	0.202	0.108	0.861	0.131		0.243	0.116	0.853	0.132	
	(1.880)	(2.793)	(17.86)	(3.331)		(2.269)	(4.771)	(26.28)	(3.449)	
Pound/$	0.133	0.147	0.792	0.051		0.219	0.185	0.690	0.087	
	(1.935)	(2.648)	(11.91)	(1.580)		(2.270)	(2.695)	(11.19)	(2.286)	
US	0.337	0.116	0.815	0.707	–0.048	0.391	0.146	0.777	0.698	**–0.062**
	(2.190)	(2.756)	(13.48)	(42.07)	(–1.199)	(2.873)	(3.593)	(16.94)	(28.58)	**(–7.053)**
Canada	0.181	0.065	0.889	–0.230		0.201	0.069	0.886	–0.256	
	(2.143)	(3.479)	(29.66)	(–8.631)		(1.816)	(2.961)	(26.70)	(–9.692)	
CN$/$	0.067	0.325	0.504	–0.151		0.254	0.254	0.686	–0.184	
	(2.567)	(3.438)	(3.689)	(–5.252)		(1.898)	(4.663)	(13.95)	(–5.780)	

Japanese currency liberalization and correlation between the U.S. and Japan

Panel B:

The following equations are simultaneously estimated. The covariance between the equity markets is augmented by the dummy variables and that between the equity and currency markets is modeled as a constant.

$R_{i,t} = b_0 + b_1R_{t-1} + b_2R_{t-2} + b_3R_{t-3} + e_{i,t}$; i = U.S. equity market, Japanese equity market, and yen/$ exchange rate

$h_{i,t} = c + a(e_{i,t-1}e_{i,t-1}) + bh_{i,t-1}$; i = U.S. equity market, Japanese equity market, and yen/$ exchange rate

$h_{i,j,t} = (r_0 + r_1 FXLIB*FXVOL_{t-1})*(\sqrt{h_{i,t}}\sqrt{h_{j,t}})$; i = U.S. equity market and j = Jananese equity market

R is the weekly return on the respective series. FXLIB is a dummy variable taking the value one in the post-liberalization period, January 1981 to December 1984 and zero otherwise. FXVOL is a dummy variable that takes the value one in periods that the volatility of the yen/dollar exchange rate is higher than its long-term average, and zero otherwise. The left-hand panel of the table reports a model without the interaction variable; i.e., the covariance is modeled with only FXLIB dummy. In the right-hand panel the interaction variable is used.

	Equity correlation and the impact of liberalization					Equity correlation and the impact of currency volatility				
	c	a	b	r_0	r_1	c	a	b	r_0	r_1
US	0.808	0.145	0.666	0.198	0.147	0.811	0.149	0.663	0.242	**0.029**
	(0.990)	(1.325)	(2.338)	(2.176)	(1.333)	(0.996)	(1.367)	(2.354)	(7.334)	**(1.815)**
Japan	0.056	0.063	0.914	–0.152		0.055	0.064	0.914	–0.156	
	(1.070)	(2.186)	(22.21)	(–3.376)		(1.273)	(2.086)	(24.89)	(–3.522)	
Y/$	0.297	0.175	0.707	–0.134		0.275	0.161	0.728	–0.138	
	(2.208)	(4.559)	(11.17)	(–3.235)		(2.311)	(2.671)	(9.357)	(–3.360)	
Loglik	–1132.580					–1133.310				

Robust t-statistics are reported in brackets below each parameter. For each system of equations, the first coefficient under r_0 is the correlation between the equity markets, the second is between the non-U.S. equity market and the exchange rate, and the third between the U.S. and the exchange rate. r_1 is the correlation between the U.S. and the other equity market induced by higher-than-usual exchange rate volatility.

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