THE STOCHASTIC CHARACTER OF JAPANESE EXCHANGE RATES

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ABSTRACT

The paper explores the stochastic character of six yen exchange rates with respect to the Canadian dollar, French franc, Italian lira, German mark, British pound and the US dollar for the 1973-2002 periods. The methodological design is the multivariate Exponential GARCH model, which is capable of capturing asymmetries in the exchange rate volatility transmission mechanism. The results point to significant reciprocal and positive volatility spillovers after the Plaza Accord of 1985. Furthermore, the finding of absence of asymmetry in the same period implies that bad and/or good news in a particular market positively and equally affects volatility in the next market.

Keywords: GARCH, volatility transmission, asymmetry, exchange rates, yen

INTRODUCTION

The considerable increase in the volatility of exchange rates since the collapse of the Bretton Woods system in 1973 is thought to create adverse effects in international transactions because it reduces trade and retards the efficient flow of international capital. Several researchers (Baillie and Bollerslev 1989, 1990, Engle et *al.* 1990, 1992, Ito et *al.* 1992, and Laopodis 1997) have investigated the patterns and the character of the volatility of individual foreign exchange markets using variants of Engle's (1982) Autoregressive Conditional Heteroskedastic (ARCH) methodology. These studies, focusing on exchange rates with respect to the U.S. dollar, documented *stylized* facts like leptokurtosis and volatility persistence as being inherent in all rates.

However, little attention has been paid to exchange rates with respect to exchange rates vis-à-vis the Japanese yen given that the majority of studies dealt with the U.S. dollar. More specifically, no attempt was made to analyze the possibility that the quantity (i.e., size) and the quality (i.e., sign) of an innovation may seriously affect the extent of volatility spillovers across markets. Recent empirical evidence involving U.S. exchange rates (Koutmos and Theodossiou 1993, and Laopodis 1997, 1998) suggests that this is very probable. For instance, it was shown that dollar depreciations increased volatility in the EMS exchange rates by more than appreciations did. This implies that markets respond asymmetrically to innovations, in the sense that negative news (i.e., exchange

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rate depreciation) in one market generates a higher volatility spillover in another market than do positive news (appreciation) of an equal size. In the context of the EMS, for instance, the original intention of the founders of EMS was that all member countries share the burden of adjustment symmetrically (van Ypersele 1979). In reality, adjustments to disequilibria were mainly undertaken by the high-inflation and high-deficit countries, and not by West Germany suggesting presence of asymmetry (Herz and Röger 1992, Gardner and Perraudin 1993).

In September 1985, ten major countries pledged to cooperate in controlling the volatility in currency exchange rates and bring down the value of the U.S. dollar in a meeting called the Plaza Accord. Two years later, the group of five (France, Germany, Japan, the UK and the US) met again to reassess their original agreement and continue their close cooperation so as to maintain stability in currency markets (the Louvre Accord). Hence, after 1985 it is expected that the behavior of these countries currencies be different in terms of duration and nature of volatility. This implies that, from an interpretational perspective, evidence of asymmetric behavior in the conditional variance of a yen exchange rate would highlight the importance of credibility in currencies (in integrated markets) and suggest a leading role of the underlying currency. Finally, evidence of persistence of news or the speed of adjustment at which these news are absorbed by a particular market is regarded as an indicator of the informational efficiency in that market.

Therefore, the purpose of this paper is to provide evidence of the level of persistence and the asymmetric nature of six major exchange rates, namely the Canadian dollar, French Franc, Italian Lira, British pound, German mark and the U.S dollar, with respect to the yen. Aside from the examination of the characteristics of the three markets, second moment market interdependencies and their asymmetry, if any, will be investigated. If these exist, it would suggest that in global marketplace news originating in a particular market is fully and efficiently transmitted to other foreign markets, thereby providing support to the 'meteor shower' thesis (Engle et al. 1990, and Ito et al. 1992). The methodological design of the study is based on the multivariate extension of Nelson's (1991) Exponential GARCH model, which is capable of explicitly modeling asymmetries potentially inherent in the volatility spillover mechanism. The model's advantage is its ability to model the three markets concurrently assuming that spillovers are realizations of a process of international news affecting any given market. This variant is appropriate for testing asymmetries in the sense that it evaluates innovations emanating from a given market in terms of magnitude and direction by the next market.

The rest of the paper is organized as follows: the next section discusses the data source and construction and reports some preliminary results involving descriptive statistics, stationarity issues, and conditional heteroskedasticity tests. The third section deals with the methodological design of the study. We next present and analyze the empirical findings and the last section summarizes the study and concludes with some remarks.

DATA AND PRELIMINARY FINDINGS

The data set consists of daily closing rates for the British pound, Canadian dollar, French franc, German mark, Italian lira, and US dollar expressed in domestic currency per Japanese yen, and extend from March 13, 1973 to August 30, 2002. The rationale for the starting date is that it coincides with the beginning of the floating exchange rate period, whilst the end point of the sample is the most current one available since the undertaking of this study. All data series are converted into marks from U.S. dollars, assuming perfect arbitrage conditions, and were taken from *DataStream*. The sample was broken into two sub periods namely from the beginning to August 30, 1985 and from September 1, 1985 to the last data point. This is necessary in order to investigate the effects of the Plaza Agreement on the extent of persistence and the nature of the yen rates' volatility.

We start the preliminary analysis with the inspection of the statistical properties of the yen exchange rates exhibited in Table 1. Following the Augmented Dickey-Fuller tests for stationarity, reported in the table, the subsequent findings were based on stationary returns. Several points are worthy of special mention. First, the variance of the pound, franc, Canadian dollar and the mark has decreased noticeably in the second period, whereas for the other two rates it increased. Second, the skewness is significant for all rates and mostly negative in the second period, and the excess kurtosis is notable in all rates in the first period. Third, the Ljung-Box statistics (for up to 10 lags) for the returns and the squared returns confirm the existence of significant linear and nonlinear dependencies in all rates in both subperiods. Finally, a test based on the Kolmogorov-Smirnov statistic rejects normality at the 5 percent level for each return series. The entire period results exhibit essentially the same characteristics in terms of high variances, kurtosis, non-normality and pronounced first- and second-order nonlinearities in all rate returns.

These findings strongly suggest the presence of a noticeable degree of asymmetry in the rates, perhaps a consequence of the presence of a time-varying second moment. This finding may be due to high kurtosis or to autoregressive conditional heteroskedasticity in the returns. In short, since these rates' distributions are skewed, the skewness coefficients provide insights about the likelihood of speculative attacks and possible chances for realignment. Speculators are interested whether skew has become more positive since in this case the probability of getting lower average earnings will have increased. The kurtosis coefficients, on the other hand, show the degree to which those probabilities have stretched to tails of the distribution, away from the center. Therefore, they provide a measure of the particular currency's weakness in the wake of external disturbances (at set par values), separate from speculation within the market. Despite these comments, these are preliminary results and they might not reveal the true structure of the returns; a more robust approach is needed, which is explained and undertaken in the next two sections.

Table 1. Preliminary Statistics

		British Pound	Canadian Dollar	French Franc	German Mark	Italian Lira	US Dollar
1st period 03/13/1973 to 08/30/1985	ADF	-5.2451	-6.0456	-6.2345	-5.8291	-5.8290	-5.7321
	Mean	0.0113	-0.0150	-0.0236	0.0183	-0.0405	-0.0091
	Var.	10.176	4.9091	8.0195	1.8118	0.7716	0.6911
	Skew.	-0.0413	0.0699	0.0373	10.714*	-0.4603*	10.104*
	Kurt.	22.834*	22.566*	21.987*	24.891*	4.8218*	37.190*
	D-stat	0.0278*	0.0340*	0.0318*	0.0340*	0.0212	0.0218
	$LB_i(5)$	110.90*	111.23*	115.89*	37.910*	432.90*	278.21*
	$LB_i(10)$	115.32*	113.31*	116.09*	40.321*	458.21*	299.11*
	$LB^2_i(5)$	114.29*	116.89*	109.21*	0.0532	610.89*	331.89*
	$LB^2_i(10)$	119.22*	120.21*	119.11*	0.0569	613.78*	353.99*
2nd period 09/01/1985 to 8/30/2002	ADF	-5.4343	-5.6556	-5.4454	-5.3221	-5.5590	-6.3221
	Mean	0.0443	-0.0144	0.0117	0.0327	-0.0125	-0.0112
	Var.	1.0246	0.7044	0.6911	0.8423	0.9276	0.7117
	Skew.	0.6454*	-0.4440*	-0.7711*	-0.0324	-0.2223*	-0.4111*
	Kurt.	3.2224*	4.4466*	4.1212*	0.5922*	2.2318*	2.8122*
	D-stat	0.0331*	0.0342*	0.0338*	0.0320*	0.0339*	0.0620*
	$LB_i(5)$	19.090*	19.553*	20.200*	46.841*	33.390*	9.7991
	$LB_i(10)$	25.132*	22.654*	28.009*	54.347*	40.921*	14.144
	$LB^2_i(5)$	70.659*	77.449*	88.921*	55.951*	77.179*	70.779*
	$LB^2_i(10)$	90.022*	89.654*	102.31*	87.221*	97.774*	90.892*
Entire period 03/13/1973 to 08/30/2002	ADF	-4.1231	-4.3433	-4.6444	-4.4332	-4.2110	-4.7344
	Mean	-0.0132	0.0143	-0.0447	0.0169	-0.0317	-0.0084
	Var.	4.3026	8.0181	7.1744	1.7338	0.8112	0.7497
	Skew.	0.0762	-0.0410*	0.0340	10.829*	-0.3813*	7.5445*
	Kurt.	18.114*	17.166*	19.187*	16.119*	3.9118*	18.010*
	D-stat	0.0211*	0.0232*	0.0218*	0.0219*	0.0217*	0.0220*
	LB(5)	131.33*	100.13*	100.29*	53.232*	72.790*	25.221*
	LB(10)	140.55*	121.31*	132.29*	57.671*	85.771*	33.333*
	$LB^2(5)$	189.29*	144.49*	155.23*	90.461*	234.89*	332.89*
	$LB^2(10)$	207.22*	165.41*	178.18*	103.20*	443.71*	432.91*

Notes: All rates in percentages; * denotes significance at the .05 level; the Kolmogorov-Smirnov D-statistic test for normality has critical value 0.0256 for the first period, 0.0212 for the second, and 0.0176 for the entire sample period; the LB's are up to 10 lags, tested for the returns as percentages and as squared, and the critical value (5% level) is 21.026.

METHODOLOGY

Given the variable construction and the preliminary data analysis in the preceding section, we are now ready to present the model for each of the daily differences of the exchange rates. The discussion below follows Laopodis (1999). Let $r_{j,t}$ be the return at time t of the yen exchange rate *j* (j=1,…, 6, where 1=Canadian dollar 2=French franc, 3=German mark, 4=Italian lira, 5=British pound, 6=US dollar), Ω_{t-1} the information set at time t-1, $\mu_{j,t}$ the conditional mean, $\sigma^2_{j,t}$ the conditional variance, $\varepsilon_{j,t}$ the innovation at time t (where $\varepsilon_{j,t} = r_{j,t} - \mu_{j,t}$) and $\xi_{j,t}$ the standardized residuals or innovations (i.e., $\xi_{j,t} = \varepsilon_{j,t} / \sigma_{j,t}$). Accordingly, the multivariate Exponential GARCH model is expressed as follows:

$$R_{i,j} \mid \Omega_{t-1} \sim (\mu, \sigma^2_{j,t}) \qquad (1)$$

$$_{i,j} = \beta_{j,0} + \sum_{i=1}^{6} \beta_{j,i}\, r_{j,t-1} + \varepsilon_{j,t} \quad \text{for } i = 1 \text{ to } 6 \qquad (2)$$

$$\sigma^2_{j,t} = exp\ \{(\alpha_{j,0} + \sum_{i=1}^{6} \alpha_{j,i}\, f_i\, (\xi_{j,t-1}) + \gamma_j\, ln\, (\sigma^2_{j,t-1})\} \text{ for i=1 to 6} \qquad (3)$$

$$f_i(\xi_{j,t-1}) = (\mid \xi_{j,t-1} \mid - E\, (\mid \xi_{j,t-1} \mid) + \delta_i\, (\xi_{j,t-1}) \text{ for i=1 to 6} \qquad (4)$$

$$\sigma_{j,i,t} = \rho_{j,t}\, \sigma_{j,t}\, \sigma_{i,t} \quad \text{for i=1 to 6 and } i \neq j \qquad (5)$$

Equation (2) represents a vector autoregressive process for each of the six exchange rate returns, in which the conditional mean in each return is influenced by its own past returns as well as those coming from the other six rates. News in market *i* become part of the information set in market *j* so it can be exploited by the home and other markets. Accordingly, coefficients $\beta_{j,i}$ for $j \neq i$, if statistically significant, reflect the extent of price (mean) spillovers across markets, i.e., the price informational efficiency. Also, significant coefficients violate the martingale hypothesis, according to which past innovations cannot be used to forecast the future movements of the series. The intercepts of the conditional mean equations correspond to the unconditional means of the raw series.

Equation (3) describes the conditional variance, which follows an Exponential GARCH process comprised of its own lagged standardized and cross-market innovations. This specification allows for shocks to influence a given market in an uneven fashion, that is, allows for volatility spillovers. The persistence of volatility is captured by γ_j. The unconditional variance exists if γ_j is less than one; if it is equal to one then it is infinite and follows an integrated process of first order (Nelson 1991). The asymmetric impact on the volatility of market *j* is modeled by means of equation (4). The partial derivatives (∂) are:

$$\partial f_i\, (\xi_{i,t}) \,/\, \partial \xi_{i,t} = -1 + \delta_i \quad \text{for } \xi_i < 0 \quad \text{and}$$

$$\partial f_i\, (\xi_{i,t}) \,/\, \partial \xi_{i,t} = 1 + \delta_i \quad \text{for } \xi_i > 0 \qquad (6)$$

Asymmetry exists if δ_i is negative and statistically significant, The term ($|\xi_{j,t}|$ - E($|\xi_{j,t}|$) measures the size effect of an innovation whilst $\delta_i(\xi_{j,t})$ measures the matching sign effect. A negative δ_i implies that a negative shock (i.e., unexpected depreciation) of an equal magnitude. The reverse holds true for positive value of δ_i. Such a result would reveal the asymmetric nature of the spillover mechanism. Further, a negative (positive) $\xi_{j,t}$ coupled with a negative δ_i enhances (reduces) the size effect. To assess the relative importance of asymmetry, the ratio of $|-1+\delta_i|/(1 + \delta_i)$ must be constructed. More importantly, coefficients $\alpha_{j,i}$ measure the volatility transmission across markets. Consequently, positive $\alpha_{j,i}$s with a negative δ_i imply, as above, that negative innovations in a particular market will exert a higher influence on the volatility of the other market(s) than do positive ones. Of course, the reverse is true for positive δ_i. Finally, the conditional variance specification presupposes constant correlation coefficients (Bollerslev, 1990). Their interpretation should be based on the fact that they measure contemporaneous relationships.

Given the above specifications and conditional on the initial values of the $r_{j,t}$, μ and $\sigma^2_{j,t}$ for t = 1,…, T = max (*p*, *q*), the log likelihood function to be maximized over the sample period(s) for the multivariate EGARCH model is expressed as follows:

$$L\,(Y \mid p,q) = \Sigma^{T}_{t=1} \log\,(\mu_t, \sigma_t) \qquad (7)$$

where (Y) is the vector of the previously specified parameters, the values of *p* and *q* are pre-specified, and μ_t and σ_t are the conditional mean and the conditional standard deviation, respectively. Since the likelihood function is highly nonlinear in its parameters numerical maximization techniques should be used to obtain the estimates. Hence we employ the procedure suggested by Berndt et al. (1974) where the asymptotic standard errors are given in the information matrix. Finally, preliminary tests pointed to a GARCH (p=q=1) process as an adequate representation of the properties of each series.

EMPIRICAL FINDINGS

The results from the estimation of equations (2) through (5) and (7) are reported in Table 2 for the both subperiods (January 13, 1973 to August 30, 1985, and September 1, 1985 to August 30, 2002). First, it can be observed that past innovations in the Canadian dollar and the franc rates do not appear to influence their own current and future values, as evidenced by the insignificance of the $\beta_{i,j}$ coefficients. By contrast, important mean spillovers are present for the lira, pound and US dollar as these countries' rates are also influenced by other countries' past innovations. Finally, with the exception of the lira's influence, all other rates affect each other in a positive way. The message from the second-moment interdependencies, however, is less informative. In particular, there is no evidence of reciprocal volatility spillovers among rates, as most of the $\alpha_{i,j}$ coefficients are statistically insignificant. Significant second moment interdependencies would signify the presence of an international, integrated marketplace in which news influencing financial data are not always internal but considerably external. This was termed as 'meteor showers', by Engle et al. (1990), according to which news originating in one foreign exchange market spills over the other markets. The empirical evidence above does not concur with this notion; rather with what Engle et *al*. called 'heat waves', whereby the major sources of disturbances are country-specific, or that a large shock increases the conditional volatility only in that country.

Table 2. Multivariate EGARCH Model Results: Mean and Volatility Spillovers

British Pound	Canadian Dollar	French Franc	German Mark	Italian Lira	US Dollar
1st period (03/13/1973 to 08/30/1985)					
$\beta_{1,0} = -0.0149$	$\beta_{2,0} = 0.0249$	$\beta_{3,0} = 0.0230$*	$\beta_{4,0} = -0.0389$*	$\beta_{5,0} = 0.0039$	$\beta_{6,0} = -0.0146$*
(0.0117)	(0.0216)	(0.0013)	(0.0031)	(0.0023)	(0.0021)
$\beta_{1,1} = -0.1910$	$\beta_{2,1} = 0.2130$	$\beta_{3,1} = 0.0135$*	$\beta_{4,1} = 0.0365$*	$\beta_{5,1} = -0.3959$	$\beta_{6,1} = 0.0266$*
(0.1418)	(0.1715)	(0.0013)	(0.0011)	(0.3219)	(0.0011)
$\beta_{1,2} = 0.0709$	$\beta_{2,2} = 0.0720$	$\beta_{3,2} = -0.0061$*	$\beta_{4,2} = 0.0589$*	$\beta_{5,2} = 0.1759$	$\beta_{6,2} = 0.0370$*
(0.0678)	(0.0593)	(0.0023)	(0.0010)	(0.1123)	(0.0021)
$\beta_{1,3} = 0.0051$	$\beta_{2,3} = 0.0473$	$\beta_{3,3} = -0.0965$*	$\beta_{4,3} = 0.0029$*	$\beta_{5,3} = 0.0047$	$\beta_{6,3} = 0.0034$*
(0.0038)	(0.0045)	(0.0011)	(0.0011)	(0.0031)	(0.0001)
$\beta_{1,4} = -0.0285$	$\beta_{2,4} = 0.1513$	$\beta_{3,4} = 0.0019$	$\beta_{4,4} = -0.1839$*	$\beta_{5,4} = -0.0159$	$\beta_{6,4} = -0.2386$*
(0.0217)	(0.1176)	(0.0013)	(0.0021)	(0.0111)	(0.0021)
$\beta_{1,5} = -0.0893$	$\beta_{2,5} = 0.1490$	$\beta_{3,5} = -0.0116$*	$\beta_{4,5} = 0.0300$*	$\beta_{5,5} = -0.1659$	$\beta_{6,5} = 0.0186$*
(0.0728)	(0.1215)	(0.0023)	(0.0081)	(0.1121)	(0.0022)
$\beta_{1,6} = 0.0424$	$\beta_{2,6} = 0.2949$	$\beta_{3,6} = 0.0069$*	$\beta_{4,6} = 0.1369$*	$\beta_{5,6} = -0.3453$	$\beta_{6,6} = 0.1826$*
(0.0378)	(0.2333)	(0.0013)	(0.0011)	(0.2819)	(0.0021)
$\alpha_{1,0} = 3.5769$	$\alpha_{2,0} = 2.1233$	$\alpha_{3,0} = 1.1523$	$\alpha_{4,0} = -0.4769$	$\alpha_{5,0} = 1.0943$	$\alpha_{6,0} = -0.7323$
(3.2925)	(1.4915)	(1.0649)	(0.4352)	(0.9710)	(0.7112)
$\alpha_{1,1} = -2.4338$	$\alpha_{2,1} = 4.1408$	$\alpha_{3,1} = 0.7541$	$\alpha_{4,1} = 0.7869$	$\alpha_{5,1} = 1.1143$	$\alpha_{6,1} = 0.7523$
(2.0376)	(3.1680)	(0.9172)	(0.6241)	(0.8871)	(0.6561)
$\alpha_{1,2} = 4.2060$	$\alpha_{2,2} = -3.5182$	$\alpha_{3,2} = 0.8071$	$\alpha_{4,2} = 0.7289$	$\alpha_{5,2} = -3.2943$	$\alpha_{6,2} = 0.6923$
(3.1521)	(3.0460)	(0.9472)	(0.7189)	(3.2210)	(0.5431)
$\alpha_{1,3} = 0.7381$	$\alpha_{2,3} = 0.7433$	$\alpha_{3,3} = 0.7444$	$\alpha_{4,3} = 0.7469$	$\alpha_{5,3} = 0.7433$	$\alpha_{6,3} = 0.7281$
(0.6600)	(0.5403)	(0.6479)	(0.7789)	(0.8891)	(0.5890)
$\alpha_{1,4} = 0.7069$	$\alpha_{2,4} = 0.7083$	$\alpha_{3,4} = 0.7113$	$\alpha_{4,4} = 0.7200$	$\alpha_{5,4} = 0.7123$	$\alpha_{6,4} = 0.7213$
(0.6500)	(0.6403)	(0.6679)	(0.7751)	(0.6141)	(0.5541)
$\alpha_{1,5} = 1.8769$	$\alpha_{2,5} = -0.4043$	$\alpha_{3,5} = 0.6423$	$\alpha_{4,5} = 0.6369$	$\alpha_{5,5} = 0.7043$	$\alpha_{6,5} = 0.6223$
(1.2600)	(0.3403)	(0.7479)	(0.7189)	(0.7711)	(0.5421)
$\alpha_{1,6} = 0.7009$	$\alpha_{2,6} = 0.6773$	$\alpha_{3,6} = 0.7093$	$\alpha_{4,6} = 0.6911$	$\alpha_{5,6} = 0.7134$	$\alpha_{6,6} = 0.7443$
(0.6415)	(0.5618)	(0.7719)	(0.6412)	(0.7010)	(0.6651)
$\delta_1 = 0.4467$	$\delta_2 = 0.5392$	$\delta_3 = 0.4492$*	$\delta_4 = 0.4438$*	$\delta_5 = 0.4470$	$\delta_6 = 0.4422$*
(0.3793)	(0.4229)	(0.0094)	(0.0021)	(0.3543)	(0.0033)

γ_1 = 0.8600*	γ_2 = 0.8570*	γ_3 = 0.5923*	γ_4 = 0.7534*	γ_5 = 0.7882*	γ_6 = 0.7135*
(0.0233)	(0.0135)	(0.0151)	(0.0121)	(0.0111)	(0.0121)
HL = 4.596	= 4.491	= 1.323	= 2.440	= 2.912	= 2.053
$\rho_{1,2}$ = 0.9520	$\rho_{2,3}$ = 0.6268	$\rho_{3,4}$ = 0.5711	$\rho_{4,5}$ = 0.6620	$\rho_{5,6}$ = 0.6780	
(0.8212)	(0.5234)	(0.5242)	(0.5151)	(0.5544)	
$\rho_{1,3}$ = 0.7020	$\rho_{2,4}$ = 0.6168	$\rho_{3,5}$ = 0.7111	$\rho_{4,6}$ = 0.6050		
(0.6212)	(0.5114)	(0.6244)	(0.5542)		
$\rho_{1,4}$ = 0.6620	$\rho_{2,5}$ = 0.8868	$\rho_{3,6}$ = 0.5811			
(0.5212)	(0.7234)	(0.4246)			
$\rho_{1,5}$ = 0.9820	$\rho_{2,6}$ = 0.6338				
(0.8212)	(0.5984)				
$\rho_{1,6}$ = 0.6820					
(0.5212)					
LF = -1237.19					

Diagnostics on Standardized Residuals						
Mean	-0.0184	-0.0112	0.0034	0.0057	0.0119	0.0208
Varian.	1.0001	0.9999	1.0001	1.0001	1.0009	1.0011
Skewn.	-0.4241*	-0.3821**	1.9934*	0.3220*	0.1723*	-0.2344*
Kurtos.	2.3246*	1.7608*	3.2191*	1.7689*	1.4381*	3.1129*
D	0.0220	0.0229	0.0230	0.0238	0.0226	0.0268*
LB(5)	6.1456	2.6123	13.451	7.2891	4.2891	13.443
LB(10)	10.211	8.1675	14.256	9.0567	8.2789	17.117
$LB^2(5)$	11.114	10.618	7.2385	11.718	3.2432	7.1189
$LB^2(10)$	12.784	12.331	10.725	11.991	5.2980	9.4331

British Pound	Canadian Dollar	French Franc	German Mark	Italian Lira	US Dollar
2nd subperiod (09/01/1985 to 08/30/2002)					
$\beta_{1,0}$ = 0.0115	$\beta_{2,0}$ = 0.0011	$\beta_{3,0}$ = 0.0131	$\beta_{4,0}$ = -0.2219*	$\beta_{5,0}$ = -0.0119	$\beta_{6,0}$ = -0.0322
(0.0017)	(0.0011)	(0.0113)	(0.0111)	(0.0013)	(0.0021)
$\beta_{1,1}$ = 0.1822*	$\beta_{2,1}$ = 0.0120	$\beta_{3,1}$ = -0.0121	$\beta_{4,1}$ = 0.0112	$\beta_{5,1}$ = -0.3211*	$\beta_{6,1}$ = 0.0622
(0.0118)	(0.0115)	(0.0113)	(0.0111)	(0.0219)	(0.0511)
$\beta_{1,2}$ = -0.0119	$\beta_{2,2}$ = 0.0112	$\beta_{3,2}$ = 0.0321	$\beta_{4,2}$ = -0.0232*	$\beta_{5,2}$ = 0.1211*	$\beta_{6,2}$ = -0.0220*
(0.0118)	(0.0133)	(0.0223)	(0.0110)	(0.0122)	(0.0121)
$\beta_{1,3}$ = 0.0111	$\beta_{2,3}$ = -0.0121	$\beta_{3,3}$ = -0.2221*	$\beta_{4,3}$ = -0.2221*	$\beta_{5,3}$ = -0.0222	$\beta_{6,3}$ = -0.0223*
(0.0118)	(0.0015)	(0.0121)	(0.0113)	(0.0111)	(0.0021)
$\beta_{1,4}$ = -0.0118	$\beta_{2,4}$ = 0.0312*	$\beta_{3,4}$ = 0.0221	$\beta_{4,4}$ = -0.2221*	$\beta_{5,4}$ = 0.0611*	$\beta_{6,4}$ = -0.3221*
(0.0117)	(0.0116)	(0.0213)	(0.0111)	(0.0111)	(0.0021)
$\beta_{1,5}$ = 0.0932*	$\beta_{2,5}$ = 0.0220*	$\beta_{3,5}$ = -0.0116	$\beta_{4,5}$ = 0.0221*	$\beta_{5,5}$ = -0.1121*	$\beta_{6,5}$ = 0.0226*
(0.0118)	(0.0105)	(0.0113)	(0.0222)	(0.0221)	(0.0122)

$\beta_{1,6}$ = 0.1124*	$\beta_{2,6}$ = 0.0112	$\beta_{3,6}$ = 0.0221	$\beta_{4,6}$ = 0.2220*	$\beta_{5,6}$ = -0.1221*	$\beta_{6,6}$ = 0.3221*
(0.0118)	(0.0113)	(0.0213)	(0.0121)	(0.0339)	(0.0121)
$\alpha_{1,0}$ = -0.2229*	$\alpha_{2,0}$ = -0.0122*	$\alpha_{3,0}$ = -0.0443	$\alpha_{4,0}$ = -0.0119*	$\alpha_{5,0}$ = 0.0118*	$\alpha_{6,0}$ = -0.0113*
(0.0225)	(0.0015)	(0.0044)	(0.0012)	(0.0011)	(0.0012)
$\alpha_{1,1}$ = -0.0228*	$\alpha_{2,1}$ = -0.0822*	$\alpha_{3,1}$ = -0.2444*	$\alpha_{4,1}$ = -0.0119*	$\alpha_{5,1}$ = -0.1013*	$\alpha_{6,1}$ = 0.0113
(0.0026)	(0.0020)	(0.0242)	(0.0131)	(0.0021)	(0.0112)
$\alpha_{1,2}$ = 0.0122*	$\alpha_{2,2}$ = 0.0332*	$\alpha_{3,2}$ = 0.2444*	$\alpha_{4,2}$ = 0.0433*	$\alpha_{5,2}$ = 0.1163	$\alpha_{6,2}$ = -0.0221
(0.0021)	(0.0030)	(0.0144)	(0.0041)	(0.1151)	(0.0231)
$\alpha_{1,3}$ = 0.0322**	$\alpha_{2,3}$ = 0.0339*	$\alpha_{3,3}$ = 0.1833*	$\alpha_{4,3}$ = 0.0144	$\alpha_{5,3}$ = 0.0113	$\alpha_{6,3}$ = -0.0622*
(0.0025)	(0.0033)	(0.0139)	(0.0129)	(0.0111)	(0.0280)
$\alpha_{1,4}$ = 0.1332*	$\alpha_{2,4}$ = 0.1033*	$\alpha_{3,4}$ = -0.0333*	$\alpha_{4,4}$ = 0.1110*	$\alpha_{5,4}$ = 0.1033*	$\alpha_{6,4}$ = 0.1121*
(0.0062)	(0.0033)	(0.0139)	(0.0111)	(0.0141)	(0.0291)
$\alpha_{1,5}$ = 0.0229*	$\alpha_{2,5}$ = 0.0233*	$\alpha_{3,5}$ = 0.2221*	$\alpha_{4,5}$ = 0.0339*	$\alpha_{5,5}$ = 0.0232*	$\alpha_{6,5}$ = -0.0322*
(0.0061)	(0.0043)	(0.0211)	(0.0139)	(0.0021)	(0.0121)
$\alpha_{1,6}$ = 0.0422*	$\alpha_{2,6}$ = 0.0343*	$\alpha_{3,6}$ = 0.0908*	$\alpha_{4,6}$ = -0.0343*	$\alpha_{5,6}$ = 0.0222*	$\alpha_{6,6}$ = 0.0232*
(0.0035)	(0.0028)	(0.0139)	(0.0122)	(0.0020)	(0.0021)
δ_1 = -0.0337	δ_2 = -0.1211	δ_3 = -0.0233	δ_4 = -0.0222	δ_5 = 0.0222	δ_6 = -0.0122
(0.0333)	(0.1129)	(0.0194)	(0.0221)	(0.0203)	(0.0123)
γ_1 = 0.9449*	γ_2 = 0.9322*	γ_3 = 0.9098*	γ_4 = 0.9221*	γ_5 = 0.9328*	γ_6 = 0.9322*
(0.0023)	(0.0033)	(0.0083)	(0.0022)	(0.0012)	(0.0022)
HL = 12.241	= 9.872	= 7.338	= 8.547	= 9.956	= 9.873
$\rho_{1,2}$ = 0.4220*	$\rho_{2,3}$ = 0.7228*	$\rho_{3,4}$ = 0.5222*	$\rho_{4,5}$ = 0.5221*	$\rho_{5,6}$ = 0.7622*	
(0.0222)	(0.0024)	(0.0122)	(0.0121)	(0.0124)	
$\rho_{1,3}$ = 0.7220*	$\rho_{2,4}$ = 0.7328*	$\rho_{3,5}$ = 0.7322*	$\rho_{4,6}$ = 0.6221*		
(0.0222)	(0.0124)	(0.0222)	(0.0022)		
$\rho_{1,4}$ = 0.7770*	$\rho_{2,5}$ = 0.8722*	$\rho_{3,6}$ = 0.6221*			
(0.0212)	(0.0024)	(0.0246)			
$\rho_{1,5}$ = 0.8220*	$\rho_{2,6}$ = 0.7228*				
(0.0022)	(0.0214)				
$\rho_{1,6}$ = 0.6532*					
(0.0122)					
LF = 234.325					

Diagnostics on Standardized Residuals						
Mean	-0.0084	-0.0031	0.0061	0.0057	0.0019	0.0014
Varian.	1.0001	1.0099	1.0001	1.0001	1.0001	1.0031
Skewn.	-0.3201*	-0.1119**	2.1114*	0.2410*	0.0711	-0.1333
Kurtos.	1.7006*	1.1118*	3.4491*	1.6711*	1.2911*	3.1329*
D	0.0200	0.0201	0.0202	0.0201	0.0203	0.0204
LB(5)	4.0446	1.1123	10.444	4.4491	2.0221	7.8043
LB(10)	6.9611	2.1175	11.211	6.9667	3.3389	9.0367
$LB^2(5)$	10.044	4.0448	5.2553	4.9744	2.2232	4.4489
$LB^2(10)$	10.124	6.9662	7.5777	5.5521	3.5580	5.4431

Notes: standard errors in parentheses; *, ** denote significance at the 5% and 10% levels, respectively; LR is the likelihood ratio, distributed a chi-square with one degree of freedom for testing normality; HL measures the half-life of a shock; the D statistic's critical value, at the 5% level, is 0.0212 for 1st subperiod and 0.0256 for 2nd subperiod; see also notes in Table 1.

The above evidence is consistent with the results of Ito and Roley (1987) who found that during the period of 1979 to 1980 there was absence of meteor showers in the yen/dollar exchange rate. They attributed this finding to the capital controls that were in place until December of 1980, following the enactment of the Foreign Exchange and Foreign Trade Control Law which dismantled all the capital controls in Japan. The effect of these restrictions was that foreign investors were prevented from trading in the Tokyo market and this insulated it from outside shocks thereby mitigating the meteor shower effect in that market.

The nature of the volatility transmission mechanism, based on the δ_i coefficients, surfaces as symmetric in the cases of the mark, lira, pound and the US dollar. This suggests that favorable or unfavorable disturbances from other markets exert the same impact on the volatility of these rates. In other words, unexpected appreciations or depreciations in a particular currency, other that the three ones above, would generate a similar impact on those three exchange rates. Finally, volatility persistence in the yen currency markets is high, as seen by the significance and the size of the γ_i coefficients. In particular, the half-life of a shock, defined as $HL= \log(0.5)/\log(\gamma_i)$, ranges from over a day for the yen/mark to over four days for the yen/Canadian dollar and yen/French franc.

As far as the second period results, there is support for statistically significant mean spillovers for the lira, pound and US dollar. Specifically, the pound and the US dollar seem to influence the conditional means of the Canadian dollar, lira, and the pound, in addition to their own (conditional) level. The German mark, on the other hand, does not surface as being affected, in its conditional mean, by any of the remaining rates although it affects the conditional means of the lira, pound and the US dollar. Moreover, there is substantial evidence of mutual and significant volatility spillovers in all yen rates, as seen by the significance of the volatility coefficients, $\alpha_{i,j}$'s. In particular, evidence of the 'meteor shower' hypothesis is implied in these rates, whereby volatility emanating from a particular market is transferred to another market. This result was expected since exchange-rate movements tend to reflect divergences in economic policies in different countries, and attempts to suppress such movements are likely to cause financial volatility elsewhere. These significant and reciprocal volatility spillovers among these six yen exchange rates also imply that there is no prevalent (dominant) player in the yen exchange market.

Finally, three other results deserve special mention. First, there is no proof of asymmetric behavior in these yen rates, as evidenced by the insignificance of the δ_i coefficients. Interestingly, most of these coefficients are negative which, if statistically significant, would suggest strong evidence of asymmetric behavior in these yen rates in the second subperiod. Second, volatility persistence has considerably increased for all yen rates. Specifically, it takes from over seven days (in the case of the mark) to over twelve days (in the case of the Canadian dollar) for a shock to persist in intensity in a particular market, relative to the first subperiod. And third, the correlation coefficients are much higher and mostly statistically significant for almost all of the rates compared to the first subperiod. This further corroborates the above findings of a much closer linkage among all of these yen exchange rates, compared to the first subperiod.

What are some of the (general) implications of the above findings? High market volatility indicates uncertainty and trading on different information sets and such volatility emanates from the prolonged uncertainty about Japan's economic prospects. The increasingly volatile yen may reflect the Japanese idiosyncratic macroeconomic situation in the 1990s compared to the rest of the world (Clarida 2000). Absence of asymmetric behavior in these rates implies that there is no dominant role for any given currency. This also suggests that positive or negative shocks to these yen exchange rates would have the same and not a differential impact on the yen and these could be adequately cushioned. Finally, the finding of greater volatility persistence in the second subperiod implies greater capital market integration which has brought with it new dangers, aside from many advantages (such as the reduction in transaction costs resulting in efficiency in the transfer of global funds). For instance, beginning in the late 1980s large institutional investors began to increasingly acquire foreign-denominated assets and this brought about intense strife to devise new products that would reduce risks and increase returns. These investors were better equipped to research the capital market conditions, so as to profitably adjust their portfolios, and this enabled them to respond much faster to market changes which generated volatility. There is evidence that since the nineties periods of exceptionally high volatility tended to take place across major bond markets and, consequently, such movements in a given market were helpful in explaining future changes in another market (Borio and McCauley 1996). Lastly, greater market integration implies a more difficult conduct of national monetary policy since shocks originating from abroad will reverberate around the capital markets in a prodigious pace, will be strong and persistent, and will limit the scope of an independent domestic monetary policy.

Statistically speaking, the residual diagnostics reveal that the EGARCH model adequately represents the dynamic interactions of the markets. Compared to the raw series in Table 1, the coefficients of skewness and kurtosis were much lower in both subperiods, evidence which supports the choice of the EGARCH model as the appropriate specification of the distribution of these yen exchange rates. Besides, the Ljung-Box statistics show no evidence of any type of time-varying dependencies and, in addition, validate the constant correlation assumption in both subperiods. Lastly, the Kolmogorov-Smirnov D statistic, for testing conditional multivariate normality in the residuals, generally rejected the null hypothesis.

SUMMARY AND CONCLUSION

The paper explored the inter-temporal interaction of six daily yen exchange rates namely the Canadian dollar, French franc, Italian lira, German mark, British pound and the US dollar from the 1973 to 2002 period. The empirical methodology used is the multivariate extension of the Exponential GARCH model, which is capable of capturing potential asymmetries in the volatility transmission mechanism. In particular, we tested for mean and volatility spillovers from one market to another and their asymmetric nature, that is, whether negative shocks originating in a given market exert a greater or a lesser impact on the next market than a positive shock of an equal magnitude. The results pointed to significant volatility spillovers from one market to another, as far as the second period (after the Plaza Accord of 1985) is concerned. These were mostly positive indicating a direct relationship between past and current volatility shocks. Thus, innovations in one currency market tend to increase volatility in the other market(s) and this occurrence is reciprocal. We did not find, however, presence of asymmetry and this denotes that bad or good news in a particular market would affect volatility in the next market equally (in any subperiod).

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