An Analysis of Daily Volatility in the Japanese Foreign Exchange Market[1]

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Abstract- **we assess the behavior of daily changes in the Japanese foreign exchange market within the framework of conditional volatility and the day of the week effects. Generalized Autoregressive Conditional Heteroscedasticity (GARCH) model is applied to let exchange rate variances change through time with detection of heteroscedastic errors in the model. Empirical results verify that volatility of the Japanese foreign exchange market is persistent, which is compared with other developed countries for the corresponding period. Moreover, the day of the week effects are present in US dollar and British Pound return series for the period January 1, 1999 to July 29, 2004. Seasonality of exchange rates in Japan foreign exchange markets may be exploitable and judged as evidence against informational efficiency of markets. Central bank intervention and interest rates are as potential sources of heteroscedastic errors in the foreign exchange rates.**

Keywords: **Volatility; Foreign Exchange Rate; ARCH / GARCH models**

I. INTRODUCTION

Exchange rate volatility has real economic costs. It affects price stability, firm profitability and the country's financial stability. The Asian financial crisis and the subsequent crises in Russia, Brazil and Turkey, all took place under "managed" exchange rate regimes. Thus, the study of volatility is of high importance to economic agents.

It has been well proved in the finance literature that any predictable pattern in returns may be available and judged as evidence against informational efficiency of markets. One statistically significant pattern in exchange rates stems from seasonality. As such, these effects in currency markets have attracted much interest and many researchers have studied daily seasonal anomalies for developed financial markets. The primary purpose of this paper is to show empirical evidence for daily volatility by examining the mean of returns in the Japanese foreign exchange market.

This paper aims to test the day of the week effects in the Japanese foreign exchange market using the conditional volatility models. Put differently, we test the weak-form efficiency at the currency market.

The rest of the paper is organized as follows: Section II is devoted to the introduction of foreign exchange market in Japan. Section III is literature review. This section will review the literature on daily changes in the foreign exchange market. Methodology and data are introduced in Section IV. Empirical results are summarized and potential sources and implications are discussed in Section V. We draw the conclusion based on the previous analysis in Section VI.

II. FOREIGN EXCHANGE MARKET IN JAPAN

Among the Asian currencies, only the Japanese yen is playing a significant international role. After the decline to 20.2% in 1998, although not reaching the former heights of the bubble era, its share worldwide rose again to 22.7% in 2001. But, this is still far behind the world's number one and two, the US dollar with 90.4% and the euro with 37.6%. Among the region's currencies, the yen is the most important one, followed by the Hong Kong dollar with a worldwide share of 2.3% and the Singapore dollar with 1.1%[2].

After World War II, Tokyo foreign exchange market reopened in 1952, and then grew into one of the three biggest markets in the world, abreast of New York and London markets, on the background of the dramatic expansion of Japanese economy and its internationalization. The Tokyo FX market with turnover of approximately USD 5 Billion per day is the world's third largest behind London and New York.

The recent turnover increase in Japan is mainly the result of a surge in cross-border swaps. In international comparison, the share of swaps in Japan, and in yen trading worldwide, traditionally is much higher than for other industrial countries. While the yen is the only Asian currency of international importance, Tokyo is not the only Asian center of foreign exchange trading. Its share of trading is 9.1% worldwide, compared to 31.1% for the UK and 15.7% for the US, followed by Singapore with 6.2% and Hong Kong with 4.1%. This is a remarkable decline from the 15.5% it held in 1989. These days, there is a fierce competition between Tokyo, Singapore and Hong Kong to become the region's leading international financial center, and, like in Europe, the volume of foreign exchange trading each of them attracts is a major determinant of competitiveness closely followed by the authorities.

The direct participants include The Bank of Japan, Banks (Japanese Banks and Tokyo Branches of Overseas Banks), and Securities Firms. Foreign Exchange Brokers operate as intermediaries between these principals. Indirect participants include, Insurance Co.'s, Import and Export Co.'s, Trading

[1] The paper has been derived from the author's master dissertation at University of Essex (see Liu (2004) for details).

[2] Source: Bank for International Settlements

Co.'s and Manufacturing Co.'s etc.

The continued broad depreciation of the US dollar was the most notable development in foreign exchange markets in 2003, 2004, and the early months of 2005. The dollar depreciated markedly against the euro and a number of other floating currencies. Its decline was particularly pronounced vis-à-vis the pound sterling and the Australian, Canadian and New Zealand dollars. By contrast, its depreciation against the yen and Asian emerging market currencies was limited. Between February and mid-May 2004, the downward trend in the US dollar partially reversed.

Conditions in foreign exchange markets in the period under review were characterised by an unusually sharp rise in overall activity, driven mainly by speculative players. A notable exception was the yen/dollar market, which appears to have experienced a decline in liquidity.

III. LITERATURE REVIEW

In finance, variance of return is important for forecasting about portfolio decisions. Many time series showing high volatility do not have a constant mean and variance whereas econometric models generally assume constant variance. There are models with serially uncorrelated process having non-constant variances conditional on the past and constant unconditional variances. In this case, conditional variance plays an important role because of time-varying structure and modeling is difficult by standard approaches since the assumptions of linear regression are violated due to misspecifications arising from wrong functional form. To deal with this difficulty, Autoregressive Conditional Heteroscedasticity (ARCH) model is recommended. This approach provides modeling volatile data since forecast variance may change over time and is predicted by past forecast errors (Engle, 1982). Various ARCH models capture changing short-run behavior due to randomness associated with different forecast periods. Moreover, the models using variance as a measure of risk are also tested with conditional variance.

Time-varying volatility is perhaps one of the most distinctive features of high frequency financial time series. The ARCH model of Engle (1982) and the GARCH of Bollerslev (1986) and the stochastic volatility models of Taylor (1982) and Jacquier et al. (1994) have proven successful in modeling such characteristics as excess kurtosis and sudden shifts in volatility of financial time series.

However, the extension of univariate ARCH, or GARCH-type (Bollerslev, 1986), model to the multivariate framework to describe covariance structure bears nontrivial difficulty since the large number of parameters must be estimated. As an alternative, Harvey et al. (1994) propose the multivariate stochastic volatility model that assumes that there are persistent movements in volatility modelled by a multivariate random walk. Their approach, however, require additional distributional assumption arising from the transformation of the original data, which is necessary to cast the model into more tractable state-space form. As Campa and Chang (1998) point out, in general comparatively little has been written on the predictability of correlation.

In order to facilitate tractable estimation of the model with time–varying covariance via a substantial reduction in the number parameters to be estimated, Diebold and Nerlove (1989) proposed a multivariate latent factor ARCH model in which the conditional variance-covariance structure of the observed variables arises from the joint dependence on a common factor. Using seven major weekly dollar exchange rates from the first week of July 1973 to the second week of August 1985, they find that a single latent variable model provides a good description of multivariate exchange rate movements.

The application of factor ARCH-type model to high frequency data like daily data, however, calls for some caution. First, the daily data appear to be subject to occasional jumps and they may not be diversifiable even in a portfolio of foreign exchange rate. The evidence of the non-diversified jump has been documented by Jarrow and Rosenfeld (1984) for index stock returns and by Kim and Chang (1996) for daily Korean size-sorted portfolios. However, this proposition has not been formally tested for the set of exchange rates to date. Hence, in addition to ARCH-type effects, transient jumps may have to be modeled explicitly in the latent factor process in high frequency data. Second, as Diebold and Nerlove (1989) point out, the presence of an ARCH effect does not have to be limited to the common factor, it would be of interest effect investigate the possible ARCH-type effects in the country-specific factors. This is particularly important because substantial variations of exchange rates may be due to transitory shocks; see, for example, Evans and Lothian (1993). If temporary shocks are mostly related to local news and if changing volatility signals varying amount of the flow of information arriving in the foreign exchange markets, it seems natural to model both market-wide factors and country-specific factors to be heteroscedastic.

On the other hand, the key focus is the estimation of volatility in a financial market. This area of study is important because an overwhelming majority of papers dealing with financial risk regard the concept of risk as an unobserved latent variable or as a useful theoretical construct to explain the behavior of asset returns. In trying to estimate daily volatility, Andersen et al. (2001a) utilized the 5-min intraday return series to estimate daily volatility and state "by summing intraday returns sufficiently frequently, the realized volatility can be made arbitrarily close to the underlying integrated volatility". They further state, "for practical purposes we can treat the daily volatility as observed, which enables us to examine its properties directly". By treating daily volatility as an observation, we have a powerful tool to analyze " a broad range of issues in financial economics, both within and beyond the realm of market microstructure" (Andersen and Bollerslev, p. 261).

A number of authors have utilized the notion of realized volatility to estimate daily-realized volatility from intraday data. Beckers (1983), Parkinson (1980) and Rogers and Satchell (1991) all propose estimators of daily volatility based upon daily high, low, opening and closing prices. Schwert (1990), Andersen and Bollerslev (1998a) and Andersen et al. (2001a) propose efficient unconditional daily volatility estimators based upon the intraday return series. The practical value of the concept of daily-realized volatility has also been extensively demonstrated in the literature. Andersen and Bollerslev (1997, 1998a) show how high frequency intraday returns contain valuable information for the measurement of volatility at the daily level. Andersen and Bollerslev (1998b) show how the concept of realized volatility can be utilized to demonstrate how standard ARCH models do in fact provide accurate volatility forecasts. Andersen et al. (2001a, b) utilize the concept of realized volatility to examine the cross-correlation in various asset returns. Moosa and Bollen (2001) utilize realized volatility to test for relationship between volatility and time to maturity in futures markets. Moosa and Bollen (2002) also employ the concept of realized volatility to test for bias in value at risk estimates. Andersen et al. (2000) show that daily returns conditioned on realized volatility are nearly Gaussian, a result consistent with the Mixture of Distributions Hypothesis. Using daily data, Canina and Figlewski (1993), Christensen and Prabhala (1998) and Gwilym and Buckle (1999) examine the information content of an option's implied volatility using realized volatility as the benchmark.

IV. DATA AND METHODOLOGY

A. Data

We rely on DATASTREAM to employ daily observation of Japanese foreign exchange rates for the period January 1, 1999 to July 29, 2004. There are 1455 observations totally. Exchange rates are expressed in the Japanese Yen against the US Dollar and the British Pound. They are computed as one hundred times the logarithmic differences of their levels.

B. Methodology

Daily returns ($R_{i,t}$) of the free market selling rates ($FX_{i,t}$) on currency i, the US dollar and the British Pound, on day t are calculated as the logarithm of exchange rate relatives:

$$R_{i,t} = \log(FX_{i,t} / FX_{i,t-1}) \quad (1)$$

We estimate the following p^{th} order autoregressive, $AR(p)$, model with deterministic daily seasonality for each currency:

$$R_{i,t} = \sum_{s=1}^{5} b_s D_s + \sum_{j=1}^{p} \phi_j R_{t-j} + u_t \quad (2)$$

Where $D_1 = 1$ if the day is a Monday and 0 otherwise; $D_2 = 1$ if the day is a Tuesday and 0 otherwise; and so on. The coefficients b_1 to b_5 of deterministic seasonal dummies are the mean returns on currency i for Monday through Friday upon removal of serial correlation.

We verify whether our models have heteroscedasticity in error terms. If one detects such effects, (Generalized) Autoregressive Conditional Heteroscedasticity (G) ARCH modeling is suitable to deal with this problem. Note that following Engle's 1982 introduction of ARCH models and their extension by Bollerslev (1986) to include GARCH models, numerous researchers have successfully applied these models for financial data. Bollerslev *et al.* (1992) provides an excellent review of the theory and empirical work on ARCH modeling in finance. Upon detection of heteroscedasticity, we rerun the model (Equation 2) by defining a time-varying variance function (h_t), which can be expressed as follows:

$$h_t = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta_1 h_{t-1} \quad (3)$$

$$u_t \sim N(0, h_t) \quad (4)$$

$$h_t = \alpha_0 + \sum_{i=1}^{q} \alpha_i u_{t-i}^2 \quad (5)$$

Equation 3 is a GARCH (1, 1) model. Equation 5 (the variance function) shows an ARCH (q) model. When ARCH models do not fit very well, then GARCH model is used by incorporating lagged variable of h_t into variance function model. Similar work has also been done by Milhoj (1987), Hsieh (1988), and Baillie and Bollerslev (1989) for daily exchange rates. As it has been well documented in the literature of this field, shifts in variance due to exogenous structural breaks can lead to spurious ARCH effects (see, for example, Lamoureux and Lastrapes (1990)). One explanation for the high degree of ARCH may be the presence of a structural break associated with some kind of crises such as a financial crisis.

Regression model with ARCH may include exogenous and lagged endogenous variables with disturbances u_t. To estimate unknown parameters, log likelihood function can be maximized via iterative scoring algorithm as

$$L_t = -1/2 \log h_t - (1/2u_t^2)/h_t \quad (6)$$

If the disturbances are conditionally heteroscedastic, maximum likelihood estimator is non-linear and more efficient than least squares. As stated in Aysoy and Balaban (1996), it is necessary to incorporate a crisis dummy into the variance function of GARCH (p,q) when there is the presence of a structural break associated that kind of crisis.

V. EMPIRICAL RESULTS AND ANALYSIS

A. Empirical Results

Following Aysoy and Balaban (1996), according to descriptive statistics for the returns on the US Dollar and the British Pound in Table 1, there is strong appearance of heteroscedasticity.

TABLE 5-1

SUMMARY STATISTICS

	US Dollar	British Pound

Maximum	0.039541	0.027253
Minimum	-0.028495	-0.028369
Mean	-8.45E-06	3.25E-05
Standard Deviation	0.006546	0.006983
Skewness	0.057724	-0.022843
Kurtosis	5.597279	4.340654
ARCH(1)(*)LM-Test	2.610084*	28.80836*
F-Test	2.611182	29.35063
ARCH(4)(*) LM-Test	15.79324*	39.07862*
F-Test	3.978023	10.00562
ARCH(8)(*) LM-Test	14.03108*	42.47045*
F-Test	1.760047	5.435408
ARCH(12)(*) LM-Test	25.55203*	44.90554*
F-Test	2.148206	3.827587

(*) All tests indicate significant ARCH effects (5%)

Using the test in Table 1, both the F-statistic and LM-statistic are very significant, suggesting the presence of ARCH in the Japanese foreign exchange rate returns on Yen to US dollars and Yen to British pound.

Moreover, Table 2 shows the results of GARCH (1, 1) with daily seasonality. We use EViews for all estimations. First, we look at the upper part of Table 2, mean function. After removal of autoregressive effects in exchange rates, there exist significant day of the week effects in exchange rates. For the period from 1 January 1999 to 29 July 2004, Wednesday, Thursday, and Friday mean returns on US dollar are statistically undistinguishable from zero. Monday has significant positive returns and Tuesday has significant negative returns at the level of 5 percent. Among these, Monday has the highest daily mean return, 0.1125 percent, which is more than six times larger than Wednesday mean return, 0.0165 percent. Like US dollar, Monday mean return on British pound is statistically significant. Friday, Thursday and Wednesday mean returns on British pound are not statistically significant although Thursday has negative returns. Monday has significant positive returns and Tuesday has significant negative returns at the level of 1 percent.

TABLE 2

GARCH (1, 1) MODEL WITH DAILY SEASONALITY

	US Dollar	British Pound
	Mean Function	
b_1	0.001125***	0.005514***
b_2	-0.001177***	-0.005717***
b_3	0.000165	0.000408*
b_4	-7.68E-05	-0.000365*
b_5	-5.82E-05	0.000158
ϕ_1	-0.160282***	0.035929
	Variance Function	
α_0	6.53E-07***	1.78E-06***
α_1	0.015225***	0.034406***
β_1	0.967392***	0.925934***

Note: ***, **, and * shows significance level at the 1%, 5%, and 10% level, respectively.

What is more, the low part of Table 2 associated with variance equation shows us the results from GARCH (1, 1) model, $h_t = \alpha_0 + \alpha_1 u_{t-1}^2 + \beta_1 h_{t-1}$.

Since GARCH (1, 1) necessitates the estimation of only two parameters among different models, it is found to be the most appropriate model. The estimated parameters are positive and significantly different from zero.

Under GARCH (1, 1) model, as in all cases, α_1= 0.015 implies that h_t is convergent. The parameter of h_{t-1}, β_1=0.967, is also highly significant indicating that variance of daily return is highly correlated. To target the persistence implied by GARCH model, it is useful to consider the sum of parameters of u_{t-1}^2 and h_{t-1} in the conditional variance model realized as 0.982, which must be less than 1.0 for the volatility process to be stationary. Convergence was satisfied and parameters of conditional variance were highly significant.

Mean returns on the British pound are significantly positive except Tuesday and Thursday. Similar to the US dollar, Monday have the highest mean returns. The interesting conclusion is to get the same results for the British pound. In GARCH (1, 1) model, the parameter of u_{t-1}^2 is 0.034 and 0.926 for the coefficient of h_{t-1}. Convergence was satisfied also and parameters of conditional variance were highly significant. For that reason, GARCH (1, 1) was selected in modeling British pound.

As stated in Table 2, both the mean returns of the US Dollar and the British Pound are significant on Monday and Tuesday at 1% significance level by using the coefficients, b_1 and b_2. Furthermore, the mean returns on Wednesday and Thursday are significant at 10% significance level also for the British Pound. And the ARCH coefficient of daily returns for the US Dollar is significant although it is negative. What is more, in GARCH (1, 1), there are same results for the US Dollar and the British Pound that variances are significant. It is obvious that there is daily seasonality with GARCH (1, 1).

Although many financial time series may exhibit a high degree of persistence in the variance of their univariate time series representations, this persistence is likely to be common among different series, so that certain linear combinations of the variables show no persistence. In that situation the variables are defined to be co-persistence in variance (Bollerslev *et al.*, 1992). The properties of exchange rate volatility are well known from previous studies that fitted GARCH models to bilateral exchange rates- see Andersen and Bollerslev (1998) and Malik (2003), for example.

B. Potential Sources and Implications

In this paper, it is found that the currency returns in the US dollar and the British pound do show volatile behavior. Namely, volatility of the Japanese daily foreign exchange rates is low. This can be explained by the behavior of economic agents who can anticipate the tendency of exchange rates during stable periods. The Central Bank intervention into the foreign exchange market is usually expected when fluctuations are high. Then, this decreases the volatility in the market. The aim to do this was to capture the transmission between exchange rates in the foreign exchange market and interest rate in the inter-bank money market in the case of low variability. It is the fact that during the volatile periods, as risk rises, risk-averse agents seek alternatives that are conditionally less risky. However, if policy makers in Japan do not create instability in the financial markets, foreign exchange rates, namely the US dollar and the British pound do not show risky behavior for the investors in the sense that volatility is low in the foreign exchange market. Our empirical results also show that seasonal effects, namely day of the week effects, exist in the foreign exchange returns.

VI. CONCLUSION

This paper analyzes the daily volatility of Japanese foreign exchange markets with ARCH / GARCH models from 1 January 1999 to 29 July 2004 over 1455 trading days. Empirical results show that the daily volatility is persistent and the day of the week effects are present in the US dollar and the British pound. Seasonal effects, namely day of the week effects, exist in the Japanese foreign exchange returns and seasonality of exchange rates may be exploitable and judged as evidence against informational efficiency of markets. At the same time, policy factors such as central bank intervention and interest rate may be some potential sources of heteroscedastic errors for foreign exchange rate volatility.

The contribution of this study is to propose a more general and realistic volatility model for the foreign exchange rate within the framework of volatility and the day of the week effect. It improves the understanding on the driving forces of the daily volatility and their influences on the daily volatility in the Japanese foreign exchange market.

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