Effects of Financial Crises on the Long Memory Volatility Dependency of Foreign Exchange Rates: the Asian Crisis vs. the Global Crisis*

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This paper examines the effects of financial crises on the long memory volatility dependency of daily exchange returns focusing on the Asian crisis in 97-98 and the Global crisis in 08-09. By using the daily KRW-USD and JPY-USD exchange rates which have different trading regions and volumes, this paper first applies both the parametric FIGARCH model and the semi-parametric Local Whittle method to estimate the long memory volatility dependency of the daily returns and the temporally aggregated returns of the two exchange rates. Then it compares the effects of the two financial crises on the long memory volatility dependency of the daily returns. The estimation results reflect that the long memory volatility dependency of the KRW-USD is generally greater than that of the JPY-USD returns and the long memory dependency of the two returns appears to be invariant to temporal aggregation. And, the two financial crises appear to affect the volatility dynamics of all the returns by inducing greater long memory dependency in the volatility process of the exchange returns, but the degree of the effects of the two crises seems to be different on the exchange rates.

Keywords: Daily Foreign Exchange Rate, Financial Crisis, Long Memory Volatility
            Dependency, FIGARCH Model, Local Whittle Method, Temporal Aggregation.
JEL Classification: C14, C22, F31, G15

I. Introduction

This paper is concerned with the intriguing effects of financial crises on the long memory volatility dependency of daily foreign exchange rates. It has been well known that many financial time series data including foreign exchange rates exhibit the long memory dependency intrinsic to their conditional variance

process with quite persistent and hyperbolic decaying autocorrelations (Baillie, 1996). And, there has been quite interest in finding the reasons and underlying causes for the empirical findings of the long memory dependency in the conditional variance process. Granger and Ding (1995) has presented that the contemporaneous aggregation of the stable Generalized Autoregressive Conditional Heteroskedasticity (GARCH) process can result in very persistent autocorrelations which is the typical feature of the long memory property. And, Andersen and Bollerslev (1997) has shown that the contemporaneous aggregation of weakly dependent information flow process can produce the long memory property in the conditional variance process.

   While some papers have argued that the aggregation is behind the long memory property and the aggregation of heterogeneous individual Autoregressive (AR) process may produce the long memory property, other papers have suggested that the observed long memory property may be generated by the presence of various types of structural breaks or regime switches in financial markets. In particular, the empirical studies including Granger and Hyung (2004) and Choi and Zivot (2007) have presented the evidence that spurious long memory can be due to the presence of occasional structural breaks detected in the financial time series, and they have conjectured that the long memory persistence may be overstated due to the presence of the structural breaks. Similarly, Granger and Terasvirta (1999) and Diebold and Inoue (2001) have presented that a process that switches the regime or switches in sign could have the characteristics of the long memory property.

   Furthermore, the financial crisis marked by several reasons including the sharp decrease in credit or the collapse of exchange rate regime generate extreme disruption of normal functions of financial and monetary system, thereby hurting the efficiency of the economy (Fratzscher, 2009; Kohler, 2010; Razin and Rosefielde, 2011; Goldstein and Razin, 2013)[1]. Clearly the last few years have been characterized by great turmoil in the world financial system. In this context, this paper focuses on the two important financial crises which affected the world foreign exchange markets significantly, the Asian crisis in 1997-1998 and the

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[1] Lamoureux and Lastrapes (1990) has suggested that the increase in volatility persistence may not be damaging to the market since the increase in the volatility persistence could be the result of increased information flow. In this sense, the financial crises could help the market efficiency in the market. Kang and Yoon (2008) has presented that the volatility persistence in Korean stock market increased during the financial crisis in 1997 since the crisis improved the information transmission in the market and the market liberalization, and the crisis helped the Korean stock market more efficient.

Global crisis in 2008-2009. During the financial crises the foreign exchange markets have experienced multiple structural breaks and regime switches caused by the sharp decrease in credit or the collapse of exchange rate regime. These intrusive events in the foreign exchange markets during the financial crises may affect the long memory volatility dependency of foreign exchange rates.

Thus, the main purpose of this paper is to investigate the interaction between the long memory dependency in the volatility process of the foreign exchange rates and the financial crises by examining the importance of the financial crises in inducing the greater long memory volatility dependency of the exchange rates. In addition, this paper provides some contributions on the volatility dynamics of the daily Korean Won (KRW)-US Dollar (USD) and the Japanese Yen (JPY)-US Dollar (USD) exchange rates. First, this paper investigates the intrinsic feature of the long memory volatility dependency of the exchange returns by using the Fractional Integrated Generalized Autoregressive Conditional Heteroskedasticity (FIGARCH) model and the Local Whittle model. In particular, this paper compares the long memory volatility dependency across various temporal aggregations of the exchange returns. Second, this paper also investigates the effects of the financial crises on the long memory volatility dependency of the exchange returns. For the purpose, this paper compares the long memory volatility dependency of the exchange returns during the three different sub-periods; the Asian crisis, the Global crisis and No crisis.

The rest of this paper is organized as follows. Section II briefly reviews the two financial crises, the Asian crisis and the Global crisis and compares them in several aspects including the place of origin and the scale of contagion. Section III describes the basic analysis on the daily KRW-USD and the JPY-USD exchange rate data and specifies two estimation models, the FIGARCH model and the Local Whittle method, for the daily exchange returns and the temporally aggregated returns over various frequencies. And, it also presents the estimation results of the long memory volatility dependency across different frequencies of the daily returns. Section IV investigates and compares the effects of the two financial crises on the long memory volatility dependency of the daily returns. Finally, section V provides a brief conclusion.

II. Reviews of Financial Crises: The Asian Crisis and the Global Crisis

The two financial crises, the Asian crisis and the Global crisis, appear to

be quite different in several ways like causes, characteristics, place of origin and scale of contagion as pointed by Kohler (2010). The Asian crisis began in the early July, 1997 with the sharp devaluation of the Thailand currency and peaked in 1998 following the closure of several important financial institutions in Asian countries including Japan and Korea. The crisis centered on the Asian economies so that its contagion was mostly confined to the Asian regions. Also, the crisis involved speculative attacks on the currencies of the Asian countries and forced the countries to abandon fixed exchange rate regimes (Jeon and Seo, 2003). There are two explanations for the Asian crisis, the fundamental based hypothesis and the financial panic hypothesis. The fundamental hypothesis presents that the unsustainable drop in macroeconomic fundamentals and the poor economic performance could be the main causes of the crisis while the financial panic hypothesis indicates a sudden and large arbitrary downward shift in market expectations and confidences as the key cause of the crisis (Kaminsky et al., 1998; Radelet and Sachs, 1998).

And, the Global crisis began by the breakdown of the US subprime mortgage industry in March, 2007 and resulted in a worldwide credit crunch since many hedge funds and banks have invested heavily in subprime mortgage backed securities. The credit crunch and credit freeze were important parts of the Global crisis as lending to firms and households decreased sharply and so did lending among banks in the interbank market. Thus, the epicenter of the crisis was the US banking system. The crisis peaked in September 2008 when the Lehman Brothers collapsed and ultimately turned out to be a disaster that imposed great losses on other firms across the industries and created turmoil not seen before. The following financial collapse in New York rapidly spread to other international financial centers, generating a huge impact on the rest of the world (Melvin and Taylor, 2009). So, the contagion was truly global.

III. Temporal Aggregation and Long Memory Volatility Dependency

This paper uses two different datasets consisting of real time daily KRW-USD and JPY-USD spot exchange rates. The two exchange rates of the KRW-USD and the JPY-USD are different in several aspects such as trading regions and trading volumes in the world foreign exchange markets. The KRW-USD exchange rates is one of the local exchange rates which are traded during several hours in a day largely in the Asian markets while the JPY-USD exchange rate is one of the key global exchange rates which are the most actively traded

during 24 hours in the world markets. So, this paper compares the long memory dependency in the volatility process of the two exchange rates, the local KRW-USD rates and the global JPY-USD rates.

In order to investigate the effects of financial crises on the exchange rates, this paper uses the datasets of the exchange rates sampled from July 1, 1997 to December 31, 2009, which includes the periods of the financial crises, the Asian crisis and the Global crisis. The daily exchange rates consist of all quotes in the Reuters network during the sample period and they are obtained from the Olsen and Associates in Zurich, Switzerland. Each quote contains a bid and an ask price for one day interval, and the daily exchange rates are calculated by linearly interpolating average between the logarithmic bid and ask prices. Also, this paper excludes the weekend data with much lower trading activities since they cannot provide any economic implications. However, this paper does not eliminate the data covering the worldwide and the country specific holidays that occurred during the sample period in order to preserve the number of returns associated with one week.

The daily exchange rates of the KRW-USD and the JPY-USD are plotted in Figure 1 (a) and (b). In the case of the daily KRW-USD exchange rates presented in Figure 1(a), the Korean won was depreciated against the US Dollar very sharply and many significant fluctuations occurred in the movements of the exchange rates during the periods of the two financial crises (Lee, 2000; Kim and Tsurumi, 2000; Jeon and Seo, 2003; Han, 2005). This seems to be due to the regime switches and the structural breaks in the foreign exchange markets caused by speculative attacks, central bank interventions and the spillover effects from other financial markets like stock markets and money markets during the crises as pointed by Jeon and Seo (2003) and Melvin and Taylor (2009). In particular, the depreciation of the Korean Won appears to be much greater during the Asian crisis than during the Global crisis.

On the other hand, the movements of the JPY-USD exchange rates presented in Figure 1(b) appear to be quite different from those of the KRW-USD exchange. One difference is that the general movements of the JPY-USD exchange rates are not as significant as those of the KRW-USD exchange rates even during the two crises. In particular, the magnitudes of the depreciation of the Japanese Yen are not as pronounced as the Korean Won even though the Japanese Yen was also depreciated against the US dollar during the Asian crisis just like the Korean Won. These movements sharply contrast with those of the Korean Won. Thus, the KRW-USD market appears to be affected by

the financial crises more significantly than the JPY-USD market.

And, the other difference is that the Japanese Yen was appreciated rather than depreciated against the US Dollar during the Global crisis, which are the opposite movements during the Asian crisis. Three explanations are presented

Figure 1. Daily exchange rates from July 1, 1997 to December 31, 2009

for the heterogeneous movements of the exchange rates during the Global crisis (Fratzscher, 2009). The first one is due to sudden reversals in the global capital flows as the investors in the US begin to withdraw capital from foreign countries to raise cash for redemptions or flight-to-safety phenomenon in which both the US and the foreign investors have shifted out of equities into fixed income instruments such as safe US government bonds and bills. The second one is related to the need for the US Dollar liquidity of the non-US firms for the loss in foreign exchange reserves among the central banks in several emerging countries and the establishment of significant numbers of swap arrangements of the US Federal Reserve with other central banks. And, the last one is the impact of carry trade strategies on exchange rates. So the unwinding of carry trade positions seems to be a prominent factor for the safe haven currencies including the Japanese Yen.

In order to figure out the underlying long memory volatility dependency in the daily KRW-USD and the JPY-USD exchange rates, this paper defines the return data of the daily exchange rates in the conventional manner from the first differences of the natural logarithm of the prices. The return at day t is defined as

$$y_t = 100 \times [\ln(s_t) - \ln(s_{t-1})] \tag{1}$$

where $t = 1,..,3423$ and s_t is the daily exchange rate at day t.

The time series realizations and the correlograms of the daily KRW-USD and the JPY-USD returns are plotted in Figures 2 and 3. Both daily returns are centered on zero but there exist obvious volatility clustering shown in Figure 2(a) and (b). The extreme turbulences in the foreign exchange markets are seen during the financial crises, which induce a heavy tailed, undefined variance of unconditional returns phenomenon as presented by Han (2005). In particular, the KRW-USD returns during the crises appear to be more volatile than the JPY-USD returns as presented in Figure 1.

Also, Figure 3(a) and (b) present the autocorrelation functions of the returns, the squared returns and the absolute returns of the daily KRW-USD and the JPY-USD exchange rates to represent the times series property. In particular, the autocorrelations of the squared returns and the absolute returns which represent the volatility process of the KRW-USD and the JPY-USD returns decay very slowly at the hyperbolic rate, which is the typical feature of the long memory dependency. The long memory volatility dependency feature is

very significant in the daily returns and is more apparent in the autocorrelation functions of the absolute returns (Baillie, 1996; Granger and Ding, 1995). And, the degree of the long memory volatility dependency seems to be stronger in the KRW-USD returns than in the JPY-USD returns as the autocorrelations of the KRW-USD returns decrease more hyperbolically. The strong long memory

Figure 2. Daily returns from July 1, 1997 to December 31, 2009
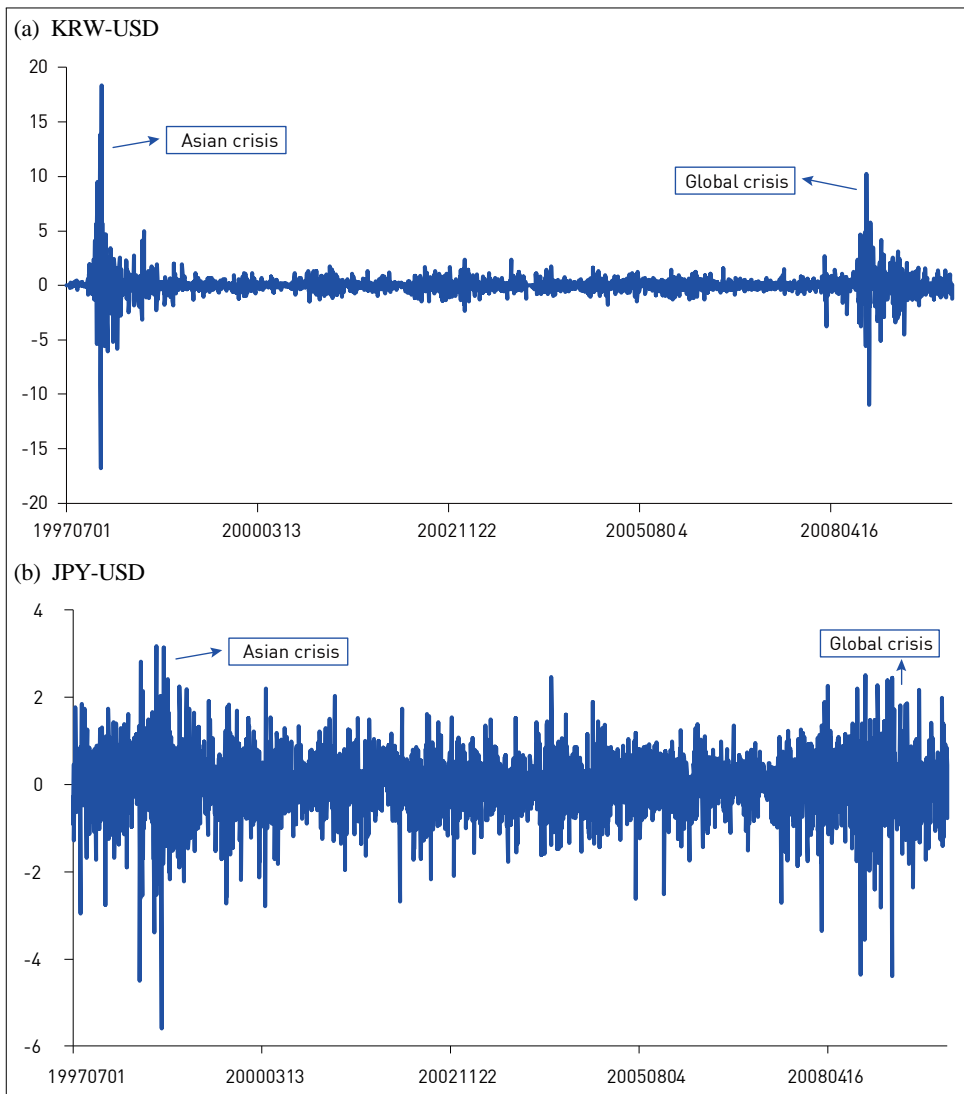
volatility dependency in the correlograms could be closely associated with the structural breaks and the regime switches in the foreign exchange markets caused by speculative attacks, central bank interventions and the spillover effects from other financial markets like stock markets during the financial crises (Granger and Hyung, 2004; Choi and Zivot, 2007).

Figure 3. Correlogram of the Daily returns
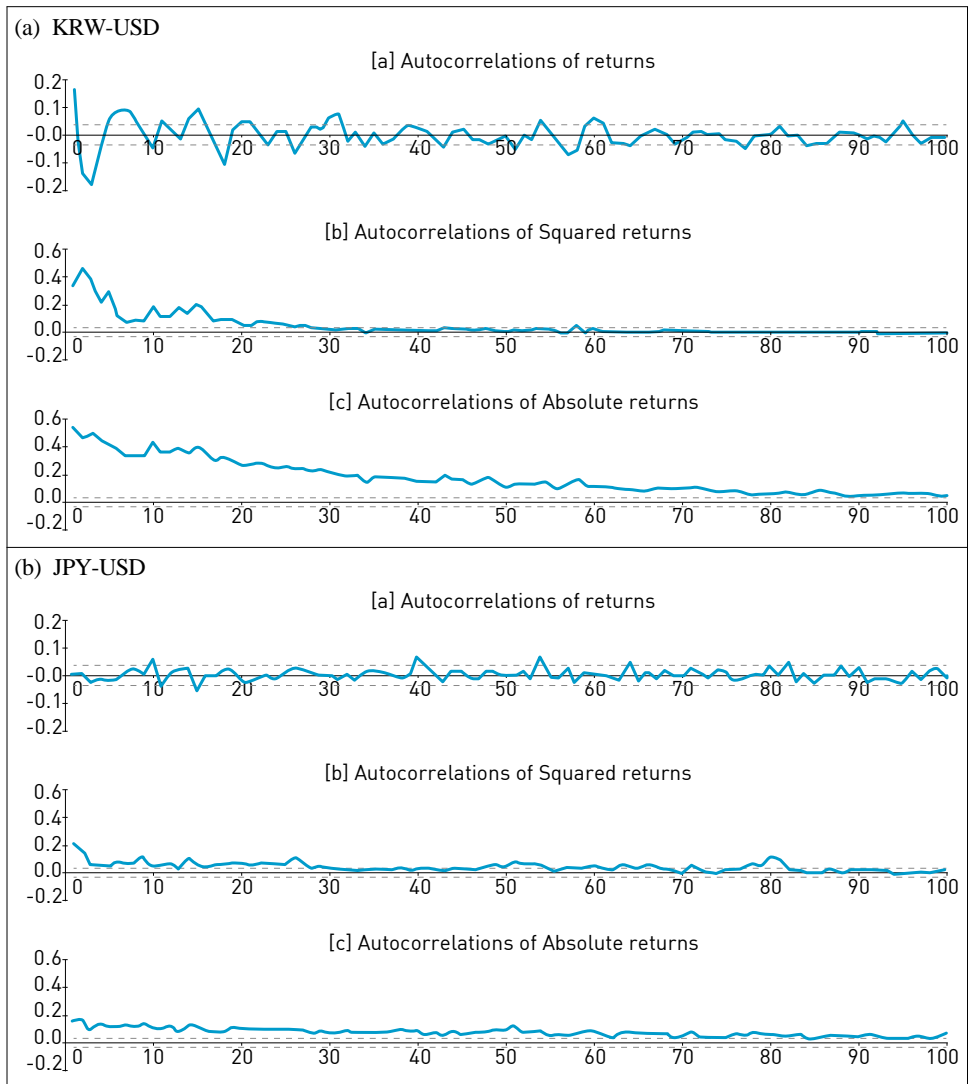
   Furthermore, this paper constructs the temporally aggregated returns of the daily returns across different frequencies from 2 days to 5 days in order to figure out the long memory volatility dependency of the daily returns and the temporally aggregated returns for the KRW-USD and the JPY-USD exchange rates. Since the long memory models can best characterize the temporal dependencies in the volatility process of foreign exchange rate as presented by Baillie et al. (2000), Baillie et al. (2004) and Han (2005)[2], this paper adopts two different long memory models, the parametric FIGARCH model (Baillie et al., 1996) and the semi-parametric Local Whittle method (Taqqu and Teverovsky, 1997 and 1998) to examine the long memory volatility dependency of the daily returns. But, the main focus of this paper is on estimating the conditional variance of the exchange returns using the FIGARCH model.

   As presented in Baillie (1996), the long memory property can be introduced in terms of a time series process. Intuitively the basic idea is based on the property of the autocorrelation function, which is defined as $\rho_k = Cov(x_t, x_{t-1})/Var(x_t)$ for integer lag k. It has been well known that a covariance stationary time series process has autocorrelations such that $\lim_{k \to \infty} \rho_k = 0$. And, the general class of the stationary and invertible time series processes has the autocorrelations that decay at the fast exponential rate, so that $\rho_k \approx |m|^k$, where this property is true for the stationary and invertible Autoregressive Moving Average (ARMA)(p, q) process.

   On the other hand, the hyperbolic decay is consistent with $\rho_k \approx c_1 k^{2d-1}$ as k gets large, with a constant c_1 and the long memory parameter d. This type of hyperbolic decay is known as the "Hurst phenomenon." The Hurst coefficient is defined as $H = d + 0.5$. For $d = 1$ or $H = 1.5$, the autocorrelation function does not decay and the series has a unit root. For $d = 0$ or $H = 0.5$, the autocorrelation function decays exponentially and the series is stationary. But for $0 < d < 1$, i.e. $0.5 < H < 1.5$, the series has a slower hyperbolic rate of decay in the autocorrelations.

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[2] Following Ding et al. (1993), several long memory volatility models have been developed to represent the long memory dependency in the conditional variance process of the financial time series data. Among them are the long memory stochastic volatility (LMSV) models of Breidt et al. (1998), the long memory autoregression conditional heteroskedasticity (LM-ARCH) models of Baillie et al. (1996) and the fractionally integrated stochastic volatility (FISV) model of Bollerslev and Wright (2000).

Among many stochastic processes which potentially exhibit the long memory property, the most widely used process is the Autoregressive Fractional Integrated Moving Average (ARFIMA)(p, d, q) model of Granger and Joyeux (1980) and Hosking (1981). In the ARFIMA process, a time series x_t is modeled as $a(\text{L})(1-\text{L})^d x_t = b(\text{L})\varepsilon_t$ where $a(\text{L})$ and $b(\text{L})$ are polynomials in the lag operator (L) with all their roots lying outside the unit circle, and ε_t is a white noise process. The ARFIMA process is stationary and invertible in the range of $-0.5 < d < 0.5$. At high lags, the ARFIMA(p, d, q) process can have an autocorrelation function that satisfies $\rho_k \approx c k^{2d-1}$. Also, the impulse response weights specified by $x_t = \sum_{k=0}^{\infty} \psi_{t-k}\varepsilon_k$ have the property for large k that $\psi_k \approx c_2 k^{d-1}$, with a constant c_2. Thus for high lags, both the autocorrelations and impulse response weights decay at very slow hyperbolic rates as opposed to the fast exponential rate associated with the stationary and invertible class of ARMA models.

While the daily exchange returns have virtually found returns to be stationary with small autocorrelations at the first few lags, the volatility process of the returns has found to be very persistently autocorrelated with long memory hyperbolic decay. The general model that is consistent with these stylized facts is the ARMA (m,n)-FIGARCH (p, d, q) process which can be specifies as,

$$y_t = \mu + \varphi(L) y_{t-1} + \theta(L)\varepsilon_t \tag{2}$$

$$\varepsilon_t^2 = z_t \sigma_t \tag{3}$$

$$[1 - \beta(L)]\sigma_t^2 = \omega + [1 - \beta(L) - \phi(L)(1-L)^d]\varepsilon_t^2 \tag{4}$$

where $z_t \sim i.i.d.(0, 1)$, μ and ω are scalar parameters, and $\beta(L)$ and $\phi(L)$ are polynomials in the lag operator. The polynomial in the lag operator associated with the moving average (MA) process is $b(L) = 1 + b_1 L + b_2 L^2 + ... + b_n L^n$, and d represents the long memory parameter.

As shown in Baillie et al. (1996), the FIGARCH model in equation (4) is derived from the standard GARCH (p, q) model. The GARCH (p, q) process

can also be expressed as the ARMA [max (p, q), p] process in squared innovations, $[1-\alpha(L)-\beta(L)]\varepsilon_t^2 = \omega + [1-\beta(L)]\upsilon_t$ where $\upsilon_t \equiv \varepsilon_t^2 - \sigma_t^2$, and is a zero mean and serially uncorrelated process which has the interpretation of being the innovations in the conditional variance. Just like the GARCH (p, q) model, the FIGARCH (p, d, q) process can also be written as $\phi(L)(1-L)^d \varepsilon_t^2 = \omega + [1-\beta(L)]\upsilon_t$ where $\phi(L) = [1-\alpha(L)-\beta(L)]$ is a polynomial in the lag operator of order max (p, q). The equation can be easily shown to transform to equation (4), which is the standard representation for the conditional variance in the FIGARCH (p, d, q) process.

The parameter (d) characterizes the long memory property of hyperbolic decay in volatility because it allows for autocorrelations decaying at a slow hyperbolic rate. The representation of equation (4) reduces to the form of the standard GARCH $(1,1)$ model when $d = 0$, and it becomes the Integrated GARCH (IGARCH) $(1,1)$ model when $d = 1$. The main attraction of the FIGARCH process is that for $0 \leq d \leq 1$, it is sufficiently flexible to allow for intermediate ranges of persistence which represents the slow hyperbolic rates of decay in the autocorrelations of the squared and the absolute returns. Furthermore, the FIGARCH process has impulse response weights, $\sigma_t^2 = \omega/(1 - \beta) + \lambda(L)\varepsilon_t^2$, where for large lags k, $\lambda_k \approx k^{d-1}$, which is essentially the long memory property of hyperbolic decay. The FIGARCH process is strictly stationary and ergodic for $0 \pounds d \pounds 1$ and shocks will have no permanent effect (Baillie et al., 1996).

Similarly to Baillie et al. (2000) and Han (2005), this paper chooses the orders of the ARMA and GARCH polynomials in the lag operator as parsimonious as possible and provides an adequate representation of the autocorrelation structure of the daily returns and the temporally aggregated returns. The above model is estimated for the daily returns and the temporally aggregated returns of interest by maximizing the Gaussian log likelihood function,

$$\ln(L;\Theta) = -(\frac{T}{2})\ln(2\pi) - (\frac{1}{2})\sum_{t=1}^{T}[\ln(\sigma_t^2 + \varepsilon_t^2\sigma_t^2)] \tag{5}$$

where Θ is a vector containing the unknown parameters to be estimated.

And, this paper uses the Quasi Maximum Likelihood Estimation (QMLE) of Bollerslev and Wooldridge (1992) for the inference, which is valid when z_t is non-Gaussian. Denoting the vector of parameter estimates obtained from maximizing (5) using a sample of T observations on equations (2), (3) and

(4) with z_t being non-normal by $\hat{\Theta}_T$, then the limiting distribution of $\hat{\Theta}_T$ is

$$T^{1/2}(\hat{\Theta}_T - \Theta_0) \rightarrow N[0, A(\Theta_0)^{-1}B(\Theta_0)A(\Theta_0)^{-1}], \qquad (6)$$

where A(.) and B(.) represent the Hessian and outer product gradient respectively, and Θ_0 denotes the vector of true parameter values.

   In particular, this paper uses equation (6) to calculate the robust standard errors with the Hessian and outer product gradient matrices being evaluated at the point $\hat{\Theta}_T$ for practical implementation since most asset returns are not well represented by assuming z_t in equation (2) is normally distributed (Baillie et al., 1996).

   After considerable experimentations the most appropriate specifications for the daily returns and the temporally aggregated returns are chosen. The estimates of the chosen models for the daily returns and the temporally aggregated returns of the KRW-USD and the JPY-USD exchange rates are presented in Table 1(a) and (b) respectively. The estimated values of the parameter (*d*) which present the long memory volatility dependency across various frequencies from 1 day to 5 days are found to range from 0.82 to 0.90 for the KRW-USD returns and from 0.30 to 0.45 for the JPY-USD returns. For all these frequencies, all the estimates of the two returns are found to be highly significant at the conventional level, and the estimated long memory volatility dependencies over different sampling frequencies are generally consistent at around 0.8 for the KRW-USD returns and 0.3 for the JPY-USD returns. These results are quite consistent with the papers of Baillie et al. (2000), Baillie et al. (2004) and Han (2005) indicating that the returns appear to be generated by a self-similarity process and that the long memory dependency could be the intrinsic feature of the exchange returns[3].

   And, the estimated log memory dependency in the volatility process of the KRW-USD returns is found to be more significant implying that the series is non covariance stationary but is still mean reverting while the long memory dependency of the JPY-USD returns is relatively smaller suggesting that the series is covariance stationary. These results seem to be consistent with the

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[3] Baillie et al.(2007) has found the similar long memory volatility property in both the daily and the high frequency commodity futures returns.

Table 1. Estimated long memory volatility dependency from FIGARCH model

(a) the KRW-USD returns and the temporally aggregated returns

	1-day	2-day	3-day	4-day	5-day
n	3423	1621	1081	810	648
μ	-0.0087 (0.0072)	-0.0176 (0.0160)	-0.0417 (0.0277)	-0.0697** (0.0311)	-0.0733* (0.0408)
θ	0.0413* (0.0228)	0.0066 (0.0228)	0.0150 (0.0439)	0.079 (0.0375)	0.0227 (0.0517)
d	**0.8316*** (0.0936)**	**0.8605*** (0.0936)**	**0.8448*** (0.1417)**	**0.9009*** (0.0652)**	**0.8298*** (0.0841)**
ω	0.0060*** (0.0021)	0.0205** (0.0085)	0.0681** (0.0329)	0.0738*** (0.0227)	0.1418*** (0.0535)
β	0.7919*** (0.0594)	0.7591*** (0.0825)	0.6013*** (0.1682)	0.6238*** (0.0828)	0.5088*** (0.1221)
φ	0.2899*** (0.0695)	0.1636* (0.0843)	-	-	-
m3	0.388	0.203	0.904	0.290	0.739
m4	6.015	5.779	7.047	5.130	5.783
Q(20)	31.403	34.145	38.896	29.923	31.703
Q^2(20)	21.883	14.062	15.236	18.047	29.689

(b) the JPY-USD returns and the temporally aggregated returns

	1-day	2-day	3-day	4-day	5-day
n	3423	1621	1081	810	648
μ	-0.0011 (0.0116)	0.0123 (0.0244)	-0.0093 (0.0369)	-0.0107 (0.0402)	-0.0186 (0.0559)
θ	0.0110 (0.0227)	-0.0091 (0.0288)	-0.0500 (0.0465)	0.0502 (0.0398)	-0.0462 (0.0357)
d	**0.3352*** (0.0766)**	**0.3069*** (0.0905)**	**0.3977** (0.1894)**	**0.3866** (0.1934)**	**0.4591* (0.2353)**
ω	0.0473* (0.0250)	0.0959* (0.0531)	0.1395 (0.0991)	0.0944 (00892)	0.0579* (0.0334)
β	0.6458*** (0.1468)	0.6549*** (0.1432)	0.6528*** (0.1257)	0.6911*** (0.1482)	0.0546* (0.0309)
φ	0.3804*** (0.1359)	0.4857*** (0.1417)	0.2416*** (0.0858)	0.4199*** (0.1238)	0.9245*** (0.0253)
m3	-0.548	-0.533	-0.887	-0.640	-0.966
m4	5.210	4.778	7.081	4.045	6.914
Q(20)	25.463	17.778	34.002	16.652	14.931
Q^2(20)	19.545	9.566	7.623	16.505	25.173

Keys: The estimation is based on the returns, $y_t = 100*[\ln(S_t) - \ln(S_{t-1})]$. The QMLE asymptotic standard errors are in parentheses below corresponding parameter estimates. The asterisks (***, ***, *) represents the significance level of 1%, 5% and 10%. The m3 and m4 represent the sample skewness and kurtosis of the standardized residuals. Q(20) and Q^2(20) are the Ljung-Box test statistics with 20 degrees of freedom also based on the standardized residuals and squared standardized residuals.

facts presented by Figure 3. The difference in the long memory dependency between the two exchange returns could be due to the differences in the characteristics of the exchange returns as presented previously. In particular, the local KRW-USD exchange rates are being traded mostly in Asian markets during only several hours in a day and the trading volume is much less than that of the global JPY-USD exchange rates traded in the world markets during 24 hours. Thus, the KRW-USD exchange rates could move more volatilely than the JPY-USD exchange rates as presented in Figure 2.

This paper also uses the semi-parametric Local Whittle estimation which could be an alternative to the parametric FIGARCH long memory models. As pointed in Robinson (1995), the advantage of Local Whittle estimation is that it allows for quite general forms of short run dynamics while the FIGARCH models are potentially sensitive to the specification used to represent the short-run dynamics. Thus, the Local Whittle estimator appears particularly desirable in situations where the long memory dependence of a time series is compounded by very non Gaussian, fat tailed densities. In particular, Taqqu and Teverovsky (1997 and 1998) report the detailed simulation studies of various semi-parametric estimators for long range dependence and find the Local Whittle estimator to perform well in extreme non Gaussian cases. And, Robinson (1995) has proved that this estimator is robust to a certain degree of conditional heteroscedasticity and more efficient than other more recent semi-parametric competitors.

Even though the semi-parametric estimation may have its own problems in the fact that it is very data-intensive and often exhibits poor performance based on the terms of bias and mean square error, this paper applies the Local Whittle estimator to the absolute return series in order to measure volatility[4] and uses it as an additional check on the presence of long memory in an alternate definition of volatility. The long memory parameter estimated from the Local Whittle method is related to, but may not be expected to be the same as the parameter estimated from the FIGARCH model.

One of the main characteristics of the long memory processes is that the spectrum of the series can be represented by $f(\omega) \sim G\omega^{-2d}$ as $\omega \to 0+$ where G is a constant (Robinson, 1995). This provides a useful objective function for estimating d which can be specified as,

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[4] The absolute returns are employed as the proxy for volatility by Ding et al. (1993), Granger and Ding (1995) and Bollerslev and Wright (2000).

$$Q = \ln\left[(1/m)\sum_{j=1}^{m} \omega_j^{2d} I(\omega_j) \right] - (2d/m)\sum_{j=1}^{m} \ln(\omega_j)$$ (7)

where $I(\omega_j)$ is the periodogram of the series at frequency ω_j. The Local Whittle estimator of d can be obtained by minimizing this objective function numerically without specifying the short run dynamics of the process in this framework. The consistency and asymptotic normality of the estimator are proved by Robinson (1995) and Phillips and Shimotsu (2001). As pointed by Robinson (1995), the choice of the number (m) of ordinates of the periodogram is the key problem in this Local Whittle method. Thus, this paper selects the values of m following the method of Shimotsu and Phillips (2000) because the optimal method for choosing the m value is not available.[5]

The estimates of the long memory volatility dependency in the daily absolute returns and the temporally aggregated absolute returns of the KRW-USD and the JPY-USD exchange rates are presented in Table 2(a) and (b) respectively.[6]

Table 2. Estimated long memory volatility dependency from Local Whittle method

(a) the KRW-USD absolute returns and the temporally aggregate absolute returns

	1-day	2-day	3-day	4-day	5-day
n	3423	1621	1081	810	648
d	0.5725*** (0.0728)	0.5663*** (0.0866)	0.5560*** (0.1024)	0.5944*** (0.1081)	0.5905*** (0.1191)

(b) the JPY-USD absolute returns and the temporally aggregate absolute returns

	1-day	2-day	3-day	4-day	5-day
n	3423	1621	1081	810	648
d	0.3344*** (0.0086)	0.3919*** (0.0117)	0.3920*** (0.0104)	0.3900*** (0.0118)	0.4414*** (0.0137)

Keys: The estimation is based on the absolute returns, $|y_t| = |100*[\ln(S_t) - \ln(S_{t-1})]|$ as the proxy for volatility. The standard errors are in parentheses below the corresponding parameter estimates. And, the asterisks (***, ***, *) represents the significance level of 1%, 5% and 10%.

[5] For the given sample size (n), this paper tries many different values of m ($m = n^{0.50}, n^{0.51} \cdots n^{0.99}$). The estimated long memory parameter initially increases and then stays around the same level as the values of m increases. Thus, the value of m is chosen when the parameter approaches to the stable level.

[6] The returns are temporally aggregated after calculating the absolute values.

The estimation results of the Local Whittle method find that the estimated values are generally consistent around 0.5 for the KRW-USD returns and 0.3 for the JPY-USD returns over various sampling frequencies and the estimated values of the KRW-USD returns are more significant than those of the JPY-USD returns. These results are quite similar to those from the FIGARCH model suggesting that the volatility dynamics of the daily exchange rates incorporates the long memory dependency and the underlying long memory volatility dependency generally appears to be consistent across various temporally aggregated returns.

It is noticeable that both the FIGARCH and Local Whittle estimates of (d) present the strong statistical evidence for the presence of long memory dependency in the exchange return volatility. Thus, the FIGARCH model appears more robust to specification of alternative representations of short-run dynamics to represent the existence of the long memory property in exchange return volatility, which is quite consistent with Han (2005).

IV. Financial Crises and Long Memory Volatility Dependency

As presented in Section I, the foreign exchange markets during the financial crises have experienced many economic/financial shocks and structural breaks related to the financial crises. These intrusive events in the foreign exchange market during the financial crises may have affected the volatility process of exchange rates (Lamoureux and Lastrapes, 1990; Melvin and Taylor, 2009). So, this paper compares the effects of the two financial crises, the Asian crisis and the Global crisis, on the long memory volatility dependency of the KRW-USD rates and the JPY-USD rates.

For the purpose, this paper specifies the periods of the two financial crises in which the foreign exchange markets are the most turbulent and also considers the period of No crisis in which the foreign exchange markets are relatively stable for the comparison. The period of the Asian crisis covers from October 1, 1997 to December 31, 1998 following Park et al. (2001) and Jeon and Seo (2003), and the period of the Global crisis covers from September 1, 2008 to November 30, 2009 based on Melvin and Taylor (2009) and Kohler (2010) while the period of no crisis is chosen from June 3, 2002 to August 29, 2003. In particular, the periods of the two crises are defined with making them contain the same size of the observations for the direct comparison.

By using the FIGARCH and the Local Whittle methods as in Section III,

this paper compares the effects of the two financial crises on the long memory volatility dependency of the KRW-USD and the JPY-USD returns. Tables 3 and 4 present the estimation results obtained from the FIGARCH model and the Local Whittle method for the effects of the Asian crisis and the Global crisis on the long memory volatility dependency of the KRW-USD returns and the JPY-USD returns respectively with comparing the estimation results of the long memory property during the period of No crisis.

Table 3. Estimated effects of the financial crises on the KRW-USD exchange rates

(a) FIGARCH model

	Asian Crisis Period (10.1.97~12.31.98)	Global Crisis Period (9.1.08~11.30.09)	No Crisis Period (6.3.02~8.29.03)
n	323	323	323
μ	0.0075 (0.0702)	-0.0490 (0.0572)	-0.0221 (0.0215)
θ	0.2740*** (0.0778)	0.0404 (0.0930)	-0.2054*** (0.0851)
d	**0.6165*** (0.1330)**	**0.4745*** (0.1800)**	**0.4640** (0.2417)**
ω	0.0213 (0.1045)	0.0254 (0.0677)	0.0042 (0.0074)
β	0.0841 (0.1335)	0.2762 (0.2966)	0.8013*** (0.1031)
φ	- -	- -	0.6006*** (0.2635)
m3	0.360	0.006	0.263
m4	4.765	4.284	4.185
Q(20)	29.580	19.407	17.617
$Q^2(20)$	16.189	18.516	23.969

Keys: the same as in Table 1

(b) Local Whittle method

	Asian Crisis Period (10.1.97~12.31.98)	Global Crisis Period (9.1.08~11.30.09)	No Crisis Period (6.3.02~8.29.03)
n	323	323	323
d	**0.4552*** (0.0312)**	**0.3809*** (0.0283)**	**0.3721*** (0.0249)**

Keys: the same as in Table 2

In Table 3 the estimates for the long memory volatility dependency of the KRW-USD returns in the periods of the Asian crisis, the Global crisis and No crisis are 0.62, 0.47, and 0.46 from the FIGARCH model and 0.46, 0.38 and 0.37 from the Local Whittle method, which are all statistically significant at the conventional level indicating that all the returns are long memory process as well. The estimated value of the long memory volatility dependency in the KRW-USD returns is found to be slightly greater in the Asian crisis period than the Global crisis period suggesting that the Asian crisis appears to affect the KRW-USD exchange rates more significantly. But the effects of the Global crisis on the KRW-USD returns may not be so significant as expected since the estimated values of the long memory volatility dependency in the Global period is not much different from that in the No crisis period.

The similar results can be found in the JPY-USD returns in Table 4. The estimates of the long memory volatility dependency of the JPY-USD returns are 0.23, 0.13, and 0.10 from the FIGARCH model and 0.35, 0.32 and 0.30 from the Local Whittle method, which are generally smaller than those of the KRW-USD returns. Even though the estimated values of the long memory volatility dependency in the JPY-USD returns are generally found to be less significant than those of the KRW-USD returns, the two financial crises are found to affect the long memory volatility dependency of the JPY-USD returns just like the KRW-USD returns. However, their effects on the JPY-USD returns could be less than those on the KRW-USD returns. Also, the effects of the Asian crisis on the JPY-USD returns appear to be more significant than those of the Global crisis and the effects of the Global crisis seem to be marginal as in the case of the KRW-USD returns.

Even though they have some limitations in providing significant economic implications due to the small values, the estimation results appear to be very informative in explaining the differences in the effects of the two financial crises on the exchange returns quantitatively. In particular, these results generally confirm the facts presented in Figures 1 and 2 which present the movements of the KRW-USD and the JPY-USD exchange rates in Section III, which implies that the volatility process is more persistent in the periods of the crises than the period of no crisis. Thus, the more significant long memory volatility dependency of the exchange returns is found to be closely related to the regime switches and the structural breaks in the foreign exchange markets associated with the financial crises. In particular, the invasive occurrences of the shocks and the breaks in the foreign exchange markets during the financial crises lasted

and increased the long memory dependency as the volatility process responded to the shocks and the breaks asymmetrically and gradually as pointed out by Andersen et al. (2002).

Table 4. Estimated effects of the financial crises on the JPY-USD exchange rates

(a) FIGARCH model

	Asian Crisis Period (10.1.97~12.31.98)	Global Crisis Period (9.1.08~11.30.09)	No Crisis Period (6.3.02~8.29.03)
n	323	323	323
μ	0.0770 (0.0597)	-0.0833* (0.0485)	-0.0133 (0.0319)
θ	0.1567* (0.0827)	-0.0389 (0.0622)	-0.0355 (0.0562)
d	**0.2257*** (0.0795)**	**0.1261*** (0.0530)**	**0.1002** (0.0563)**
ω	0.3103*** (0.1085)	0.4403*** (0.1692)	0.1757 (0.1093)
β	0.0458 (0.1076)	0.0894 (0.0613)	0.1520 (0.1041)
m3	-0.597	-0.717	-0.268
m4	4.020	6.311	3.769
Q(20)	23.100	24.689	12.570
$Q^2(20)$	10.981	15.674	11.551

Keys: the same as in Table 1

(b) Local Whittle method

	Asian Crisis Period (10.1.97~12.31.98)	Global Crisis Period (9.1.08~11.30.09)	No Crisis Period (6.3.02~8.29.03)
n	323	323	323
d	**0.3517*** (0.0208)**	**0.3177*** (0.0193)**	**0.3029*** (0.0193)**

Keys: the same as in Table 2

Thus, the estimation results indicate that there occurred more shocks and more breaks in the foreign exchange markets during the Asian crisis than during the Global crisis and that the KRW-USD market seems to be more volatile than the JPY-USD market during the financial crises because of the shocks and the

breaks occurred in the KRW-USD market. One possible reason is that the financial markets in Korea like stock and money markets became liberalized and the daily exchange rate margin in the Korean foreign exchange market was abolished during the Asian crisis. As a result, the KRW-USD foreign exchange market has become more closely related with the other financial markets. Thus, the spillover effects from the other financial markets to the KRW-USD exchange market seem to increase more significantly and cause the exchange rate volatility to be more asymmetric during the Asian crisis (Kim, 2001; Jeon and Seo, 2003; Han 2005).

V. Conclusion

This paper considers the long memory volatility dependency of the daily KRW-USD and the JPY-USD exchange returns and the effects of the two financial crises, the Asian crisis and the Global crisis, on the long memory volatility dependency of the two exchange returns. In order to investigate the long memory dependency in the volatility process, this paper estimates the daily and temporally aggregated returns of the two exchange rates by using the parametric FIGARCH model and the semi-parametric Local Whittle estimation method. This paper finds that the estimates of the long memory dependency in the volatility process of the two returns are generally invariant to various time aggregations indicating that the returns could be generated by a self-similarity process and that the long memory dependency could be the intrinsic feature of the exchange returns.

Then, this paper has analyzed the effects of the financial crises on the long memory volatility dependency of the daily returns. The estimation results of this paper show that the long memory volatility dependency of both the KRW-USD and the JPY-USD returns are greater during the periods of the financial crises than the period of No crisis providing statistical evidence to support the conjecture that the shocks and the breaks associated with the financial crises are partly responsible for inducing greater long memory dependency in the volatility process of foreign exchange returns. In particular, the estimates of the long memory dependency during the Asian crisis are found to be greater than those during the Global crisis indicating that the Asian crisis affected the exchange rates more significantly than the Global crisis, and the long memory dependency of the KRW-USD returns is found to be greater than that of the JPY-USD returns suggesting that the KRW-USD market experienced more

economic/financial shocks and more structural breaks associated with the crises than the JPY-USD market.

Thus, this paper implies that the volatility dynamics of exchange rates appears to incorporate long memory dependency but the long memory component might be different depending on the trading region or the trading volume of exchange rates, and that the financial crises could affect the volatility dynamics of exchange returns by inducing the greater degree of the long memory volatility dependency of exchange returns. This paper seems to be useful in understanding the effects of financial crisis on foreign exchange rate dynamics by distinguishing the underlying forces behind the long memory property in the volatility process of exchange.

Also, the findings of this paper imply that financial crises tend to overestimate the long memory property in the volatility process of exchange rates, leading to potential errors in interpreting the foreign exchange risks in foreign exchange markets. In this context, this paper could be useful for foreign exchange traders and policy makers who design the optimal portfolio strategy or policy in order to manage the foreign exchange risks involved in the foreign exchange markets during financial crises. For example, the traders and the policy makers can successfully manage their foreign exchange risks during financial crisis if they could predict the movement of exchange rates correctly based on the accurate forecasts of the volatility dynamics incorporating the long memory dependency and the financial crises.

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