Structural Breaks and Long Memory Property in Korean Won Exchange Rates: Adaptive FIGARCH Model*

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This paper explores the issue of structural breaks and long memory property in the conditional variance process of the Korean exchange rates. To analyze the above in detail, this paper examines the dynamics of the structural breaks and the long memory in the conditional variance process of the Korean exchange returns by using the daily KRW-USD and KRW-JPY exchange rates for the period from 2000 through 2007. In particular, this paper employs the Adaptive FIGARCH model of Baillie and Morana (2009) which account for the structural breaks and the long memory property together. This paper also finds that the new Adaptive FIGARCH model outperforms the usual FIGARCH model of Baillie et al. (1996) when the structural breaks are present and that the long memory property in the conditional variance process of the Korean exchange returns is significantly reduced after the structural breaks are accounted for. Thus, these results suggest that the upward biased long memory property observed in the conditional variance process of the Korean exchange returns could partially have been imparted as a result of neglecting the structural breaks.

Keywords: Daily Korean foreign exchange rates, FIGARCH model, Adaptive FIGARCH model, Long memory property, Structural breaks

JEL Classification: C15, C22, G1

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본 논문은 한국원화 환율의 조건부 분산과정에서 나타나는 구조적 변화와 장기기억 특성에 대해 살펴보았다. 이를 위해 2000년부터 2007년 기간 동안의 일별 원-달러와 원-엔 환율을 이용하여 원화 환율수익률의 조건부 분산과정에서 나타나는 구조적 변화와 장기기억 특성의 역학적 관계를 분석하였다. 특히 본 논문에서는 구조적 변화와 장기기억 특성을 함께 고려하는 Baillie and Morana(2009)의 Adaptive FIGARCH 모형을 이용하였다. 분석결과 본 논문은 새로운 Adaptive FIGARCH 모형이 구조적 변화가 존재할 경우 Baillie et al.(1996)의 일반적인 FIGARCH 모형보다 뛰어나며 구조적 변화를 고려할 경우 원화 환율수익률의 조건부 분산과정에서 나타나는 장기기억 특성이 감소함을 발견하였다. 따라서 본 연구결과 원화 환율수익률의 조건부 분산과정에서 관측된 상향 편향의 장기기억 특성이 부분적으로는 구조적 변화를 고려하지 못함으로써 발생되는 것임을 제시하였다.

핵심용어: 일별 원화 환율, FIGARCH model, Adaptive FIGARCH model, 장기기억 특성, 구조적 변화

JEL 분류: C15, C22, G1
I. Introduction

This paper is concerned with a new approach to examining the long memory property and the structural breaks in the conditional variance process of Korea’s daily exchange rates. In particular, this paper applies the Adaptive FIGARCH or A-FIGARCH model of Baillie and Morana (2009) which is designed to account for both the long memory property and the structural breaks. For this purpose, this study uses the daily exchange rates of Korean Won (KRW)-US Dollar (USD) and Korean Won (KRW)-Japanese Yen (JPY) for the period from 2000 through 2007, and investigates the dynamics of the structural breaks and the long memory in the conditional variance process of the Korean exchange rates.

As pointed out by Baillie (1996), it has been well known that most daily and high frequency financial time series data including foreign exchange rates exhibit long memory properties intrinsic to their conditional variance process with persistent and hyperbolic decaying autocorrelations. Long memory properties have been presented in their squared returns (Ding et al. 1993; Granger and Ding 1996), power transformations of absolute returns (Lobato and Savin 1998), conditional variance (Baillie et al. 1996) and other measures of volatility such as realized volatility (Ebens 1999; Andersen et al. 2003). Following Ding et al. (1993) and Dacorogna et al. (1993), several long memory volatility models have been developed to represent the long memory property 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) and Harvey (1998), and the long memory autoregression conditional heteroskedasticity (LM-ARCH) models of Baillie et al. (1996), Bollerslev and Mikkelsen (1996) and Davidson (2004).

Even though these models have appeared to be useful in describing the long memory property in the conditional variance process, there has been more interest in finding the reasons and underlying causes for the empirical findings of the long memory property in the conditional variance process. For example, Granger and Ding (1996) have presented that the contemporaneous aggregation of the stable
GARCH(1,1) process can result in very persistent autocorrelations which is the typical feature of the long memory property. And, Andersen and Bollerslev (1997) have shown that the contemporaneous aggregation of weakly dependent information flow process can produce the long memory property in the conditional variance process. In the high frequency perspectives, Müller et al. (1997) have presented that the long memory property in volatility can result from the reaction of short term dealers to the expected volatility trend, which cause persistence in the conditional variance process.

However, other papers have cast doubts on the validity of the empirical findings of the long memory property in the conditional variance process (Mikosch and Starica 1998; Diebold and Inoue 2001; Granger and Hyung 2004; Choi and Zivot 2007). Most of them have suggested that the observed long memory property in conditional variance process may be generated by the presence of various types of structural breaks or regime switches. Mikosch and Starica (1998), Granger and Hyung (2004) and Choi and Zivot (2007) have presented evidence that spurious long memory could be due to the presence of occasional structural breaks detected in the financial time series, and they have conjectured that the long memory persistence of the conditional variance process may be overstated due to the presence of those structural breaks. And, Starica and Granger (2004) have found that a non-stationary model with allowance for breaks in the unconditional variance can outperform a long memory model in forecasting. 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 a long memory property.

Thus, it could be necessary to consider both the structural breaks and the long memory property in the conditional variance process of financial time series data. Following the paper of Diebold (1988) and Lamoreaux and Lastrepes (1990) which have initially suggested that the occurrences of the structural breaks in conditional variance process can generate extreme persistence, the subsequent papers by Lobato and Savin (1998), Beine and Laurent (2000), Morana and Beltratti (2004) and Martens et al. (2004) have presented that an appropriate model for the conditional
variance process of financial time series data should include both long memory property and structural breaks.

Given the previous studies summarized above, this paper focuses on the possibility that both the structural breaks and the long memory property are likely to be present in the conditional variance process of the daily Korean exchange rate returns obtained from the KRW-USD and the KRW-JPY daily exchange rates. First, this paper estimates the long memory property in the conditional variance process of the Korean exchange returns by using the long memory FIGARCH model of Baillie et al. (1996). This paper finds that there exists strong evidence for long memory property in the conditional variance process of the Korean exchange returns, which can be caused by some economic changes in the Korean economy during the sample period even without serious financial crises. In particular, the long memory property in the conditional variance process of the KRW-USD returns appears to be more persistent than that of the KRW-JPY returns.

Second, this paper examines both the structural breaks and the long memory property in the conditional variance process of the daily Korean exchange returns by applying the Adaptive FIGARCH (A-FIGARCH) model which has recently been proposed by Baillie and Morana (2009). The A-FIGARCH model augments the standard FIGARCH model with a deterministic component following Gallant (1984)’s flexible function form. Thus, the A-FIGARCH model appears quite useful in analyzing the conditional variance process of the Korean exchange returns by allowing for both the stochastic long memory component and the deterministic structural break component. In particular, the A-FIGARCH model has the advantage of being computationally straightforward since the model does not require pre-testing for the number of structural break points nor does it require any smooth transition between volatility regimes as Baillie and Morana (2009) have presented.

This paper finds that the A-FIGARCH model outperforms the usual FIGARCH model when the structural breaks are present and that the degree of the long memory property in the conditional variance process of the Korean exchange
returns is significantly reduced after the structural breaks are accounted for. This finding suggests that the part of the observed long memory property in the conditional variance process could be overstated by the structural breaks.

The rest of this paper is organized as follows. Section II presents the descriptive statistics of the daily Korean exchange returns and shows the significant long memory feature in the conditional variance process of the Korean exchange returns by providing results from the estimation of the usual FIGARCH model. Section III reports the estimation results of the A-FIGARCH model to account for both the structural breaks and the long memory property in the conditional variance process of the Korean exchange returns and provide evidence that the observed upward biased long memory property in the conditional variance process of the Korean exchange returns could be imparted partially as a result of neglecting the structural breaks. Then section IV concludes.

II. Long Memory Property and FIGARCH Model

This section is concerned with some of the intriguing features of the daily Korean exchange returns obtained from the KRW-USD and the KRW-JPY spot exchange rates. In particular, it explores some aspects of the long memory property in the conditional variance process of the Korean exchange which has been well documented in the papers of Lee (2000), Han (2003) and Jo and Lee (2004). It focuses on the long memory parameters estimated from the FIGARCH model of Baillie et al. (1996). The FIGARCH model has been shown to provide good descriptions of the conditional variance process for the daily Korean exchange rates return by several previous studies such as Jo and Lee (2004) and Han (2003).

The data sets of the KRW-USD and the KRW-JPY daily spot exchange rates are obtained from Olsen and Associates for the sample period of January 3, 2000 through December 31, 2007.¹ Each quotation consists of a bid and an ask price

¹) The daily KRW-JPY exchange rates are obtained from the cross exchange rates of the
and is recorded in time to the nearest second. Following the procedures of Baillie et al. (2000, 2004), the spot exchange rate for each daily interval is obtained by the average of the log bid and the log ask. Excluding weekends and worldwide holidays like Christmas and New Year’s Day, the spot exchange rates form a sample of 2075 observations.

As presented in Figure 1 (a) and (b), the daily exchange rates of the KRW-USD and the KRW-JPY show very significant movements even without any serious

![Figure 1. Daily Korean Spot Exchange Rates](image-url)

KRW-USD and the JPY-USD exchange rates.
financial crises like the Asian crisis in 1997 and the Credit crisis in 2008 over the sample period. Over the period from 2000 to 2004, the Korean Won has generally remained depreciated against the US Dollar and the Japanese Yen because the Korean economy had been facing many economic challenges compounded by a global economic slowdown and suffered from weak domestic investment, slow economic growth and rising unemployment. But, the value of Korean Won has risen since late 2004 as the Korean economy became stronger due to the strong growth in exports but the world economy has still remained weak. In particular, the Korean exchange rates appear to contain several structural breaks caused by the economic challenges that occurred in the Korean economy during the sample period even without some serious financial crises.

And, the returns of the daily exchange rates are defined in a conventional manner as continuously compounded rates of return and calculated as the first difference of the natural logarithm of prices. The return ($y_t$) at day $t$ is defined as

$$y_t = 100 \times [\ln(P_t) - \ln(P_{t-1})]$$

(1)

where $t = 1, \ldots, 2075$ and $P_{t,n}$ is the spot exchange rate at day $t$.

The details of the descriptive statistics for the daily returns of the KRW-USD and the KRW-JPY spot exchange rates are provided in Table 1. The sample means

|                      | KRW-USD   | KRW-JPY   |
|----------------------|-----------|-----------|
| Mean                 | -0.0092   | -0.0139   |
| Standard Deviation   | 0.4394    | 0.6224    |
| Q(20)                | 25.9371   | 66.8421   |
| Q^2(20)              | 480.4750  | 81.1987   |
| Skewness             | 0.2243    | 0.2466    |
| Kurtosis             | 5.7345    | 4.7907    |
| $\rho_1$             | -0.0651   | -0.1602   |

Note: The Q(20) and Q^2(20) are the Ljung-Box test statistics at 20 degrees of freedom based on the returns and the squared returns. $\rho_1$ is the first order of autocorrelation.
of the daily KRW-USD and the KRW-JPY return are found to be -0.009 and -0.014 respectively, which are very close to zero and indistinguishable at the standard significance level given the sample deviations of 0.439 and 0.622. And, the daily KRW-USD and the KRW-JPY exchange returns appear not to be normally distributed since the values of the skewness are 0.224 and 0.247, and the values of the kurtosis are 5.735 and 4.791, which are greater than the levels of the normal distribution, and they are all statistically significant.2)

In particular, the Ljung-Box test statistics for the test of the serial correlations, $Q^2(20)$, calculated from the squared returns of the KRW-USD returns and the KRW-JPY exchange rates are 480 and 81, which are statistically significant indicating the existence of highly persistent autocorrelations in the conditional variance process. The problem of the serial correlation seems to be more significant in the KRW-USD returns than in the KRW-JPY returns. Thus, the conditional variance process of the KRW-USD returns appears to be more persistent relative to the KRW-JPY returns. Also, there exists small and negative first order of autocorrelations in the Korean exchange returns. This may be due to the market microstructure effects (Andersen and Bollerslev 1997, 1998) or large outliers in the data (Goodhart and Figliuoli 1991; Goodhart and Giugale 1993; Ghosh 1997).

These findings can be confirmed by Figures 2 and 3 which plot the time series realizations and the correlograms of the daily KRW-USD and the KRW-JPY spot exchange. In Figure 2 (a) and (b), both returns are centered on zero but there exist obvious volatility clustering. And, the extreme turbulences in the market are also seen to induce a heavy tailed, undefined variance of unconditional returns phenomenon, as studied by Koedijk et al. (1990). And, in Figure 3 (a) and (b) which present the autocorrelation function of the returns, squared returns and absolute returns of the daily KRW-USD and the KRW-JPY exchange rates, the first order autocorrelation in the returns is small and negative for the Korean exchange returns while higher order autocorrelations of the raw returns are not significant at conventional levels.

2) According to Jarque and Bera (1987), the standard errors of the sample skewness and the sample kurtosis in their corresponding normal distributions are $(6/T)^{1/2}$ and $(24/T)^{1/2}$. 
The autocorrelations of the squared returns and the absolute returns decay very slowly at the hyperbolic rate, which is the typical feature of the long memory property. The long memory feature of the Korean exchange returns is very significant in the autocorrelations of the squared and absolute returns of the daily KRW-USD and the KRW-JPY returns and is more visible in the autocorrelation functions of the absolute returns as presented by Granger and Ding (1996). And, the degree of the long memory property seems to be more significant in the KRW-USD returns than the KRW-JPY returns.
Figure 3. Correlograms of Daily Korean Spot Returns

(a) KRW-USD

(a) Autocorrelations of Daily KRW-USD Spot Returns

(b) Autocorrelations of Squared Daily KRW-USD Spot Returns

(c) Autocorrelations of Absolute Daily KRW-USD Spot Returns

(b) KRW-JPY

(a) Autocorrelations of Daily KRW-JPY Spot Returns

(b) Autocorrelations of Squared Daily KRW-JPY Spot Returns

(c) Autocorrelations of Absolute Daily KRW-JPY Spot Returns
A model that is consistent with these stylized facts is the MA(1)-FIGARCH (1,d,1) process,

$$y_t = \mu + \theta e_{t-1} + \epsilon_t$$  \hspace{1cm} (2) \\
$$\epsilon_t^2 = z_t \sigma_t$$  \hspace{1cm} (3) \\
$$(1 - \beta L) \sigma_t^2 = \omega_t + [1 - \beta L - \phi L (1 - L)^d] \epsilon_t^2$$  \hspace{1cm} (4)

As presented by Baillie et al. (1996) and Baillie and Morana (2009), it is well known that for $0 < d \leq 1$, the FIGARCH process has an undefined unconditional variance. However, the process does possess a finite sum to its cumulative impulse response weights. This makes the FIGARCH model different from other possible forms of long memory ARCH models proposed by Karanassos et al. (2004). But the FIGARCH model appears to be strictly stationary and ergodic for $0 < d \leq 1$ (Baillie et al. 1996).

In particular, the FIGARCH process has impulse response weights, $\sigma_t^2 = \omega_t (1 - \beta) + \gamma (L) \epsilon_t^2$, where for large lag $k$, $\gamma_k \approx c k^{d-1}$ where $c$ is a positive constant. Thus, the conditional variance can be expressed as a distributed lag of past squared unconditional disturbances with coefficients that decay at a slow, hyperbolic rate, which is essentially consistent with the long memory property, or “Hurst effect” of hyperbolic decay. Thus, the attraction of the FIGARCH process is that for $0 < d < 1$, it is sufficiently flexible to allow for intermediate ranges of persistence.

3) The exact parametric specification of the model that best represents the degree of autocorrelation in the conditional mean and the conditional variance is chosen based on the Box-Pierce portmanteau statistics. The test statistics shows that the models specified for the Korean exchange returns do a good job of capturing the autocorrelations in the mean and volatility of the return series. In each case there is no evidence of additional autocorrelation in the standardized residuals or squared standardized residuals, indicating that the chosen model specification provides an adequate fit.
The above model is estimated for the daily Korean exchange returns of interest by maximizing the Gaussian log likelihood function,

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

where \( \Theta \) is a vector containing the unknown parameters to be estimated.

The consistency and asymptotic normality of the QMLE for the conditional variance process can be established on the basis of available results from the estimation of GARCH processes as pointed out by Baillie and Morana (2009). Thus, the inference is usually based on the QMLE of Bollerslev and Wooldridge (1992), which is valid when \( \epsilon_t \) 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 \( \epsilon_t \) being non-normal by \( \hat{\Theta}_T \), then the limiting distribution of \( \hat{\Theta}_T \) is

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

where \( A(.) \) and \( B(.) \) represent the Hessian and outer product gradient respectively, and \( \Theta_0 \) denotes the vector of true parameter values.

Equation (6) is used to calculate the robust standard errors that are reported in the subsequent results in this paper, with the Hessian and outer product gradient matrices being evaluated at the point \( \hat{\Theta}_T \) for practical implementation.

Table 2 presents the estimation results of applying the above model for the Korean exchange returns. In particular, the long memory parameters (d) in the conditional variance process are estimated to be 0.53 and 0.28 for the KRW-USD and the KRW-JPY returns, and are found to be statistically significant at the
conventional level. It presents strong support for the existence of the long memory property in the conditional variance process of the Korean exchange returns even though there were not any serious financial crises during the sample period. The long memory property seems to be closely related to the structural breaks caused by economic changes in the Korea economy during the periods concerned. These results confirm the fact represented in Figure 3 that the daily Korean exchange returns contain the long memory property in the conditional variance process and

| Table 2. Estimated MA(1)–FIGARCH (1,d,1) Model for the Daily Korean Spot Returns |
|-----------------|-----------------|-----------------|
|                 | KRW-USD         | KRW-JPY         |
| \( \mu \)      | -0.0121          | -0.0229***      |
|                 | (0.0075)         | (0.0106)        |
| \( \theta \)   | -0.0398          | -0.1774***      |
|                 | (0.0263)         | (0.0227)        |
| \( d \)        | 0.5314***        | 0.2772***       |
|                 | (0.1773)         | (0.1021)        |
| \( \omega \)   | 0.0040**         | 0.0280          |
|                 | (0.0023)         | (0.0176)        |
| \( \beta \)    | 0.7242***        | 0.6062***       |
|                 | (0.1097)         | (0.1191)        |
| \( \varphi \)  | 0.4041***        | 0.4335***       |
|                 | (0.1152)         | (0.1173)        |
| \( \ln(L) \)   | -1035.855        | -1893.876       |
| Skewness        | 0.542            | 0.317           |
| Kurtosis        | 6.331            | 4.412           |
| Q(20)           | 15.003           | 13.859          |
| Q^2(20)         | 18.412           | 25.300          |

Note: QMLE asymptotic standard errors are in parentheses below corresponding parameter estimates. \( \ln(L) \) is the value of the maximized log likelihood. The sample skewness and kurtosis refer to the standardized residuals. The Q(20) and Q^2(20) statistics are the Ljung-Box test statistics for 20 degrees of freedom to test for serial correlation in the standardized residuals and squared standardized residuals. (*, **, *** ) denote the statistical significance at 10%, 5% and 1% level respectively.
the long memory property in the KRW-USD returns is more significant than that in the KRW-JPY returns. Thus, the long memory property is the characteristic feature in the conditional variance process of the daily Korean exchange returns.

Furthermore, the values of the Q(20) and the $Q^2(20)$ which are the Ljung-Box test statistics for the test of the serial correlations in the residuals and the squared residuals are found to be 15.00 and 18.41 for the KRW-USD and 13.86 and 25.30 for the KRW-JPY returns showing that the model specified for the daily Korean returns does a good job of capturing the autocorrelations in the conditional mean and the conditional variance of the daily return series. In each case there is no evidence of additional autocorrelation in the standardized residuals or squared standardized residuals indicating that the chosen model specification provides an adequate fit. And, a sequence of diagnostic portmanteau tests on the standardized residuals and squared standardized residuals failed to detect any need to further complicate the model. Thus, this basic FIGARCH model seems to match the dynamics of the daily Korean exchange returns.

III. Long Memory Property, Structural Breaks and Adaptive FIGARCH Model

As presented in the introduction, many previous studies have provided abundant motivations to allow for the possibility of the structural breaks in the conditional variance process of financial time series data including foreign exchange rates. This section considers the possibility of the structural breaks caused by some economic...
changes in the Korea economy along with the long memory property in the conditional variance process of the daily Korean exchange returns by applying the Adaptive FIGARCH or A-FIGARCH model of Baillie and Morana (2009).

One of the quite powerful approaches to account for the structural breaks is to allow the intercept to be time varying as suggested by Baillie and Morana (2009). They have provided that the A-FIGARCH model can be derived from the usual FIGARCH model of Baillie et al. (1996) by directly allowing the intercept in the conditional variance equation to be time varying according to the flexible functional form of Gallant (1984) and Andersen et al. (1997). The flexible function form model can allow for a very efficient modeling of structural breaks since it does not require any pretests to determine the actual location of break points nor add any estimation complexity. Hence, the A-FIGARCH process is formed from two basic components of a long memory volatility process and a deterministic time-varying intercept which allows for the breaks. Although the deterministic process modeled by the flexible functional form is smooth, it has been shown to be able to approximate accurately quite abrupt structural breaks.

The general A-FIGARCH \((p,d,q,k)\) model becomes,

\[
[1 - \beta(L)](\sigma_i^2 - \omega_i) = [1 - \beta(L) - \phi(L)(1 - L)^d] e_i^2
\]

where

\[
\omega_i = \omega_0 + \sum_{j=1}^{k}\left[\gamma_j \sin(2\pi j t / T) + \delta_j \cos(2\pi j t / T)\right]
\]

5) There are also GARCH models allowing to model time varying unconditional moments such as the flexible coefficient GARCH model of Medeiros and Veiga (2004), the spine GARCH model of Engle and Rangel (2008) and the smooth transition model of Terasvirta and Gonzalez (2006). But, this paper focus on the FIGARCH model since the FIGARCH model is essentially a generalization of the GARCH model that allows the differencing parameter to be fractional with the hyperbolic memory and imposes fewer burdens in computation (Baillie and Morana 2009).
In order for the conditional variance to be positive with nearly certainty at each point in time, restrictions similar to those holding for the standard FIGARCH \((p,d,q)\) model have to be imposed. The inclusion of the time-varying incept component implies that the A-FIGARCH model is neither ergodic nor strictly stationary. One of the great advantages of the above A-FIGARCH model concerns the relative simplicity of computation. The computation burden is only marginally greater than estimating the standard FIGARCH model.

The estimation is relatively straightforward, and the joint presence of the long memory and the structural break can be assessed by standard hypothesis tests of the fractional differencing parameter and the deterministic trigonometric components. Moreover, Baillie and Morana (2009) have found that the A-FIGARCH model shows a superior performance relative to the usual FIGARCH model in terms of bias and root mean square error (RMSE). See Baillie and Morana (2009) for more details and the simulation results of the A-FIGARCH model.

Hence, this paper adopts the A-FIGARCH model in order to account jointly the long memory property and the structural breaks in the conditional variance process of the daily Korean exchange returns. While the mean process of the daily Korean exchange returns is still specified as following an MA(1) process as in section 2, the conditional variance process is represented by the A-FIGARCH \((1,d,1,k)\) model with the trigonometric term \((k)\) for the flexible functional form, which is the simplest version and appears to be quite useful in practice as suggested by Baillie and Morana (2009). This model can be written as;

\[
y_t = \mu + \theta \varepsilon_{t-1} + \varepsilon_t \tag{9}
\]

\[
\varepsilon_t^2 = z_t \sigma_t \tag{10}
\]

\[
(1 - \beta L)\sigma_t^2 = \omega_t + \left[1 - \beta L - \phi L (1 - L)^d\right] \varepsilon_t^2 \tag{11}
\]
\[
\omega_t = \omega_0 + \sum_{j=1}^{k} \left[ \gamma_j \sin(2\pi j t / T) + \delta_j \cos(2\pi j t / T) \right]
\]  \hspace{1cm} (12)

The Gaussian loglikelihood function of the model is the same as the MA(1)-FIGARCH(1,d,1) model in Section II. And, the estimation and inference for the parameters of the above model can be facilitated by the same method of QMLE by numerically maximizing the loglikelihood function with respect to the parameters as in Section II. The procedure can implement simultaneous estimation of all the model’s parameters including those in the flexible function form which specify the time varying intercept in the conditional variance process. In particular, for the practical implementation of the model, one important consideration is the determination of the trigonometric terms (k) in the flexible functional form. In this paper, the trigonometric terms (k) selected are 10 for the KRW-USD returns and 9 for the KRW-JPY returns based on the Schwartz Information criterion (SIC).\(^6\)

The estimation results of the above model for the daily Korean exchange returns are reported in Table 3. In particular, the parameters of the long memory property in the conditional variance process are estimated to be 0.14 and 0.06 for the KRW-USD and the KRW-JPY returns, respectively, and they are all statistically significant. It could be seen that the long memory parameters are significantly reduced compared to the estimated parameters under the basic FIGARCH model without considering the structural breaks, indicating that the degree of the long memory property in the conditional variance process can be upward biased and overstated when the structural breaks caused by economic changes in the Korean economy are neglected.

Also, the Loglikelihood Ratio (LR) test statistics, denoted by LR, for testing the

\(^6\) One interesting issue concerns the interpretation of the structural breaks whether or not they correspond to certain important economic changes like the changes in the interest rates, inflation, and economic growth by the economic policies. However, without more detailed information, it is difficult to distinguish these breaks. Furthermore, no formal test is available for detecting multiple structural breaks in the long memory I(d) process with unknown number of breaks (Granger and Hyung 2004).
### Table 3. Estimated MA(1)–Adaptive FIGARCH (1,d,1,k) Model for the Daily Korean Spot Returns

|      | KRW-USD | KRW-JPY |
|------|---------|---------|
| $\mu$ | -0.0115 (0.0070) | -0.0212** (0.0105) |
| $\theta$ | -0.0367 (0.0239) | -0.1789*** (0.0223) |
| $d$ | 0.1441*** (0.0386) | 0.0626* (0.0366) |
| $\beta$ | 0.7090 (0.4346) | 0.3035 (0.3405) |
| $\gamma$ | 0.7212* (0.4265) | 0.2685 (0.3902) |
| $\omega_0$ | 0.1113** (0.0465) | 0.2936*** (0.0711) |
| $\gamma_1$ | 0.0316 (0.0265) | 0.0312 (0.0243) |
| $\delta_1$ | -0.0262 (0.0271) | -0.0151 (0.0227) |
| $\gamma_2$ | 0.0455** (0.0230) | 0.0334 (0.0270) |
| $\delta_2$ | 0.0220 (0.0193) | 0.0139 (0.0250) |
| $\gamma_3$ | -0.0651** (0.0321) | -0.0565* (0.0293) |
| $\delta_3$ | -0.0225 (0.0213) | 0.0112 (0.0255) |
| $\gamma_4$ | 0.0025 (0.0180) | -0.0227 (0.0236) |
| $\delta_4$ | -0.0088 (0.0202) | 0.0006 (0.0252) |
| $\gamma_5$ | 0.0187 (0.0195) | -0.0178 (0.0231) |
| $\delta_5$ | 0.0203 (0.0162) | 0.0405 (0.0340) |
| $\gamma_6$ | -0.0535* (0.0292) | 0.0757** (0.0364) |
null hypothesis of FIGARCH versus A-FIGARCH data generating process, are found to be 41.63 and 45.75 for the KRW-USD and the KRW-JPY returns, respectively. Under the null, the LR statistics follow an asymptotic $\chi^2$ distribution and the FIGARCH model is rejected for the Korean returns at standard significance levels. And, no evidence of serial correlation or instability can be detected in the
conditional variance process of the Korean exchange returns from the Ljung-Box test statistics, $Q^2$ with the values of 9.33 and 25.42, respectively, for the KRW-USD and the KRW-JPY returns. These test statistics support the fact that the inclusion of the trigonometric components facilitates improvement of the general goodness of fit of the model and that the A-FIGARCH is superior to FIGARCH for modeling jointly the structural breaks and the long memory property in the conditional variances of the daily Korean exchange returns, which is consistent with the findings of Baillie and Morana (2009). Thus, there we can find the improvement in fit and the reduction in the long memory parameters once the structural breaks and the long memory property are jointly modeled.

IV. Conclusion

This paper considers the daily KRW-USD and KRW-JPY exchange rates over the period from 2000 through 2007. Special attention is devoted to account for both the structural breaks caused by economic changes in the Korean economy and the long memory property in the conditional variance process of the Korean exchange returns during the sample period.

Initially, this paper uses the usual FIGARCH model of Baillie et al. (1996) to figure out the long memory property in the conditional variance process of the daily Korean exchange returns series. This paper finds strong evidence for hyperbolic decay and significant persistence of autocorrelations in the conditional variance process of the daily Korean returns, a feature typical of the long memory property. Thus, the long memory property is found to be the characteristic feature in the conditional variance process of the daily Korean exchange returns. And, the usual FIGARCH model of Baillie et al. (1996) is found to provide an adequate fit and match the dynamics of the daily Korean exchange returns. In particular, the long memory property in the conditional variance process, the KRW-USD returns are more significant than that in the KRW-JPY returns.
Following many previous studies which have allowed for the possibility of structural breaks in the conditional variance process of financial time series data including foreign exchange rates, this paper applies the A-FIGARCH model of Baillie and Morana (2009) which is designed to provide a model for both structural breaks and the long memory property in the conditional variance process of the daily Korean exchange returns. In particular the structural breaks can be molded by allowing the intercept in the conditional variance equation to follow a slow time-varying function specified by the flexible functional form of Gallant (1984) and Andersen et al. (1997).

A-FIGARCH model outperforms the usual FIGARCH model when the structural breaks are present and it can provide significant gains in terms of bias and efficiency in estimating the long memory property in the conditional variance process. It could be seen that the long memory parameters are significantly reduced under the A-FIGARCH model compared to the estimated parameters under the FIGARCH model. Thus, the observed upward biased long memory property in the conditional variance process of the daily Korean returns could be imparted by neglecting the structural breaks caused by certain economic changes in the Korean economy.

Consequently, the results of this paper show the usefulness and the superiority of the A-FIGARCH model relative to other available modeling strategies for its value in terms of risk estimates, especially if the timing and the size of the breaks are shown to be predictable when the breaks are endogenous and need to be explored further.
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한영욱(韓永郁)

현재 한림대학교 경제학과 부교수로 재직 중이다. 미국 미시간주립대학교(Michigan State University)에서 경제학 박사학위를 취득하고, 2001년부터 2004년까지 City University of Hong Kong에서 조교수를 역임하였다. 주요 연구분야는 계량경제학(시계열분석)과 국제금융 등이다. 주요 논문으로 “High Frequency Deutsche Mark - US Dollar Returns: FIGARCH Representations and Non Linearities”, Multinational Finance Journal (2000), “On Testing Target Zone Models Using Efficient Methods of Moments”, Journal of Business and Economic Statistics (2001), “Further Long Memory Properties of Inflationary Shocks”, Southern Economic Journal (2002), “Merging the Stochastic with the Nonlinear Deterministic: the Case of High Frequency European Exchange Rates”, Journal of International Financial Markets, Institutions and Money (2004), “Long Memory Volatility Dependency, Temporal Aggregation and Korean Currency Crisis: the Role of High Frequency Korean Won-US Dollar Exchange Rates”, Japan and the World Economy (2005) 등이 있다.
