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Long Memory Property and Central Bank Intervention during the Currency Crisis in the Daily Korean won-US dollar Exchange Rates*

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This paper considers the use of the long memory volatility process, FIGARCH, in representing Korean won – US dollar daily spot exchange rates. The spot returns are found to exhibit the widespread long memory property in their conditional variances and the FIGARCH model appears to be appropriate to represent the volatility process of the daily returns. The estimated long memory parameter during the crisis is found to be greater than that of the post-crisis period. This paper also quantifies the effectiveness of the interventions by the Bank of Korea (BOK) during the crisis. General conclusions provide evidences that the interventions of the BOK during the crisis were not effective in preventing depreciation of the Korean won and that they did not have any effect on market volatility. This study also finds that the interventions did not influence the risk premium or excess returns over uncovered interest parity (UIP).

JEL Classifications: C22, F31

Keywords: daily Korean won-US dollar exchange rates, long memory property, FIGARCH model, central bank intervention.

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1. INTRODUCTION

Recently the long memory and persistent property in volatility process has become a well documented feature of the foreign exchange. But, little is known about Korean exchange rates so that this property is studied by using a set of daily foreign exchange rate data on the Korean won vis a vis the US dollar. The exchange rate returns are found to exhibit the widespread long memory and persistent property in both their conditional variances and their absolute returns. The long memory volatility parameter is estimated using the FIGARCH model of Baillie *et al.* (1996) which has been found to provide good descriptions of daily return volatility. The estimated long memory parameter is found to be more persistent during the crisis period compared to the post-crisis period.

Intervention activity has been used by many central banks like the US Federal Reserve Bank, the Bundesbank and the Bank of Japan, especially at the end of the 1980s and the early 1990s. Recently the central banks of Asian countries like Korea, Thailand and Malaysia have intervened during the currency crisis. Despite its widespread use as a policy instrument, there has been controversy about the effectiveness of intervention as a policy tool, whether it can achieve the policy objectives of either influencing the level of nominal exchange rates or reducing their volatility. In particular, some papers like Sachs and Woo (2000) and Kim (2000) have reported that the inappropriate interventions and the problematic exchange rate policies of Asian countries may be one of the main causes of the currency crisis in 1997. In this context, the events in the Korean currency market, especially during the crisis, throw some light on the controversy of recent years about the effectiveness of central bank intervention.

This paper investigates the direct quantitative effect of the interventions in the foreign exchange market which were undertaken by the Bank of Korea (hereafter BOK) during the period of the currency crisis in Korea, and explores whether the interventions are effective as a policy tool. And, following Baillie and Osterberg (1997b), this paper briefly discusses the issue

of whether the interventions of the BOK can help explain the risk premium over UIP (uncovered interest rate parity) during the crisis.

The plan of the rest of this paper is as follows: section 2 estimates some long memory ARCH, or FIGARCH models of the spot returns series, which are found to provide a good description of the volatility process of the returns series. The long memory parameter of the post-crisis period is also estimated for comparison. Section 3 presents the literature reviews on central bank interventions and theoretical transmissions, and provides econometric evidence on the effects of the interventions of the BOK during the crisis. Section 3 also briefly discusses the impacts of the interventions on the deviation of the nominal exchange rate from UIP (uncovered interest rate parity). Section 4 then provides a brief conclusion of the paper.

2. ANALYSIS OF DAILY KOREAN WON-US DOLLAR RETURNS

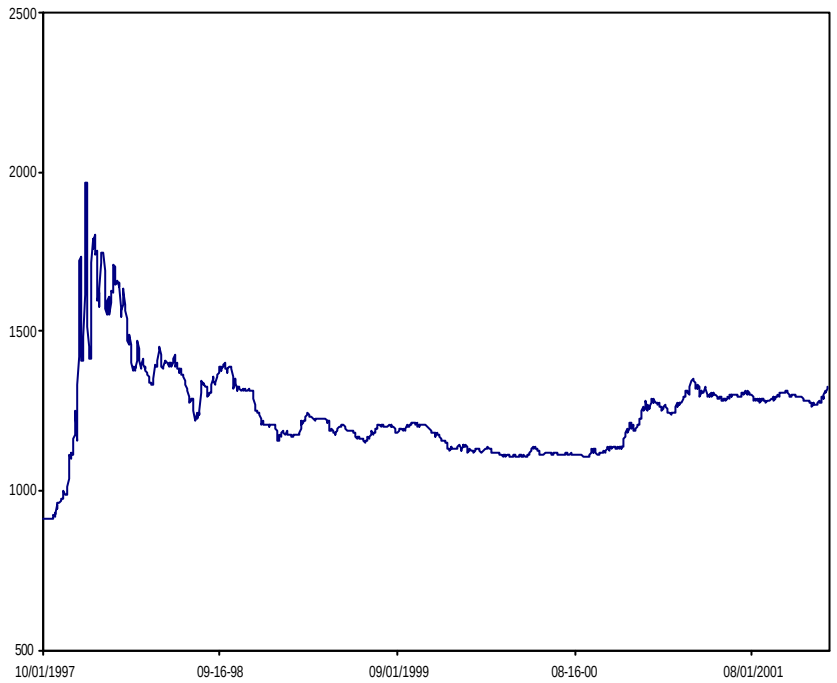
This section is concerned with some of the intriguing features of daily Korean won-US dollar foreign exchange rates. In particular, it explores some aspects of the property of long memory and persistent volatility that has become a well documented feature of these markets (Dacorogna *et al.*, 1993; Andersen and Bollerslev, 1997 and 1998; Baillie *et al.*, 2000; Baillie and Han, 2002a, b). It focuses on the long memory volatility parameter obtained by estimating the FIGARCH model of Baillie *et al.* (1996) from the daily returns data. Such models have been found to provide good descriptions of daily return volatility by several previous studies such as Baillie and Han (2002a,b), Beine *et al.* (2002a, b), Baillie and Osterberg (2000b) and others.

The set of the daily Korean won- US dollar spot exchange rates is obtained from Datastream for the sample period of October 1, 1997 through December 31, 2001, which covers the period of the currency crisis in Korea.[1)]

[1)] Even though the Asian currency crisis started on July 2, 1997 in Thailand, Park *et al.* (2001) defines the crisis period in Korea from October 1, 1997 to September 30, 1998 and the post

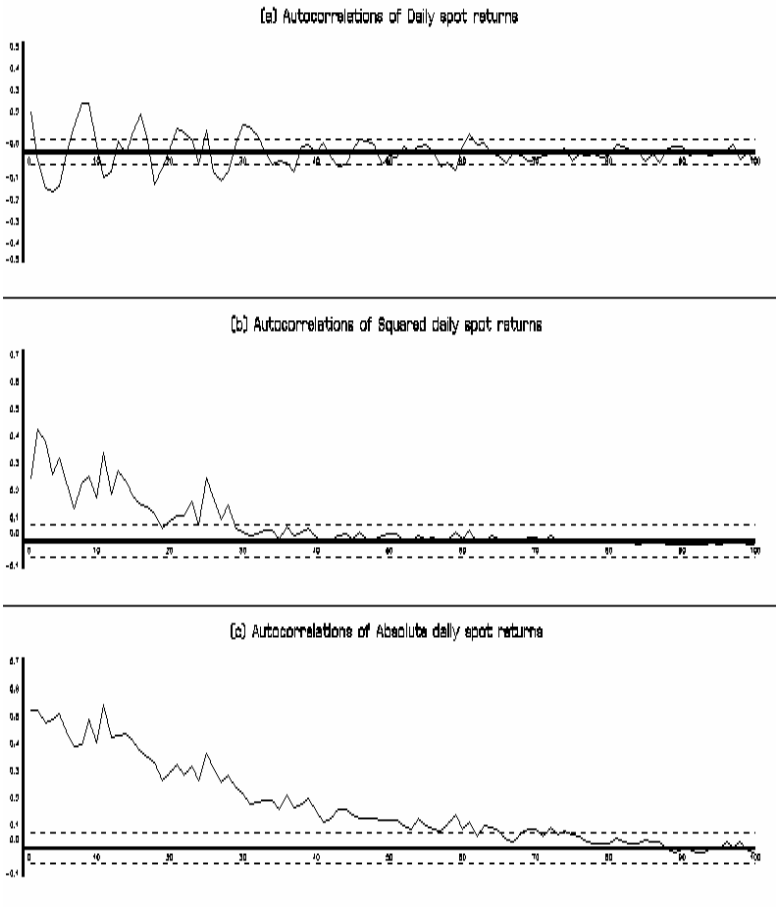
Excluding weekends, the spot returns realize a sample of 1109 daily observations. The time series realizations of the daily spot exchange rates are plotted in Figure 1. The extreme turbulence in the market is also seen to induce a heavy tailed, undefined variance of unconditional returns phenomenon, as studied by Koedijk *et al.* (1990). The autocorrelation function of the daily returns, squared returns and absolute returns are plotted in Figure 2. In particular, the autocorrelations of the squared returns and absolute returns exhibit very slow and persistent decay that is typical of asset prices determined in speculative auction markets (Ding *et al.*, 1993).

Figure 1 Daily W-US$ Spot Exchange Rate
(from October 1, 1997 through December 31, 2001)



crisis period as starting from October 1, 1998.

Figure 2 Correlograms of Daily W-US$ Spot Returns



The model that is postulated to describe the returns process is then,

$$R_t = 100 \times \Delta \ln(S_t) = \varepsilon_t + \theta \varepsilon_{t-1}, \tag{1}$$

$$\varepsilon_t = z_t \sigma_t, \tag{2}$$

$$\sigma_t^2 = \omega + \beta \sigma_{t-1}^2 + \left[1 - \beta L - (1 - \gamma L)(1 - L)^d\right] \varepsilon_t^2, \tag{3}$$

where S_t is the daily Korean won-US dollar spot exchange rate, z_t is i.i.d.(0,1) and the returns are specified to follow a MA(1) process, while the conditional

variance process σ^2_t, in equation (3), is represented by a FIGARCH (Fractionally Integrated Generalized AutoRegressive Conditional Heteroskedastic) process, as developed by Baillie *et al.* (1996). The above FIGARCH(1, d, 1) process is sufficiently general that it can generate a very slow hyperbolic rate of decay in the autocorrelations of squared returns. When $d = 0$, then equation (3) reduces to the standard GARCH(1, 1) model; and when $d = 1$, then equation (3) becomes the Integrated GARCH, or IGARCH(1, 1) model, and implies complete persistence of the conditional variance to a shock in squared returns. The FIGARCH process has impulse response weights, $\sigma^2_t = \omega/(1 - \beta) + \delta(L)\varepsilon^2_t$, where for large lags k, $\delta_k \quad k^{d-1}$, which is essentially the long memory property or "Hurst effect" of hyperbolic decay. The impulse response weights of the FIGARCH process for the daily exchange rates are presented in Figure 3 and compared with those of the GARCH and the IGARCH process.[2] The attraction of the FIGARCH process is that for $0 < d < 1$, it is sufficiently flexible to allow for intermediate ranges of persistence. The process is strictly stationary and ergodic for $0 \le d \le 1$, and shocks will have no permanent effect.[3] The simpler FIGARCH(1, d, 0) process is of the form,

$$\sigma_t^2 = \omega + \beta\sigma_{t-1}^2 + \left[1 - \beta L - (1-L)^d\right]\varepsilon_t^2 .$$

The equations (1) through (3) are estimated by using non-linear optimization procedures to maximize the Gaussian log likelihood function,

$$\log(L) = -(T/2)\ln(2\pi) - (1/2)\sum_{t=1,T}\left[\ln(\sigma_t^2 + \varepsilon_{et}^2\sigma_t^2)\right], \qquad (4)$$

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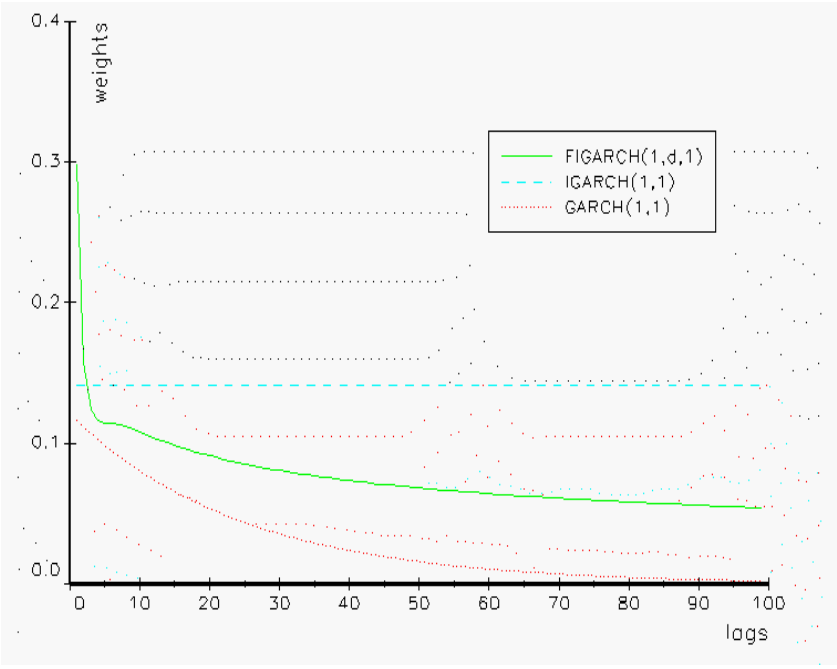
[2] Similarly, Baillie *et al.* (2002) and Beine *et al.* (2002a) have compared the cumulative impulse response functions of the conditional variance process for the estimated FIGARCH model with those of the GARCH and IGARCH models for CPI inflation rates and DM-$ exchange rates.

[3] Analogous behavior in the conditional mean of exchange rates has been considered by Cheung (1993).

Figure 3 Cumulative Impulse Weights for Conditional Variance of the Daily won-US$



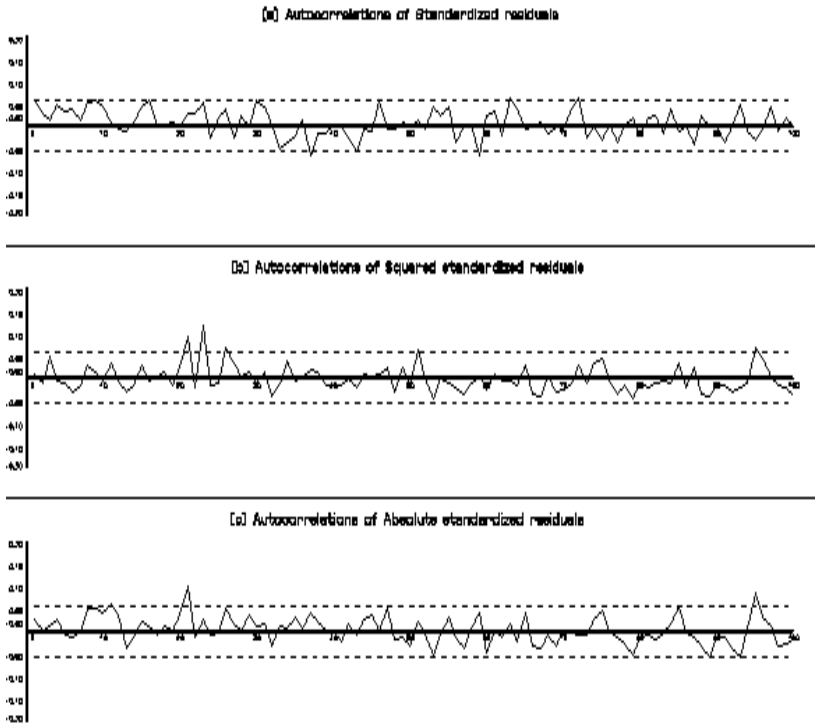
with respect to the vector of parameters denoted by $\grave{e}$. Since most spot returns series are not well described by the conditional normal density in (4), subsequent inference is consequently based on the Quasi Maximum Likelihood Estimation (QMLE) technique of Bollerslev and Wooldridge (1992), where

$$T^{1/2}(\hat{\boldsymbol{q}}_T - \boldsymbol{q}_0) \Rightarrow N\{0, A(\boldsymbol{q}_0)^{-1} B(\boldsymbol{q}_0) A(\boldsymbol{q}_0)^{-1}\}, \tag{5}$$

and $A(.)$ and $B(.)$ represent the Hessian and outer product gradient respectively; and $\grave{e}_0$ denotes the true parameter values.

Figure 4 presents correlograms of the standardized residuals from the estimated MA(1)-FIGARCH (1, $\ddot{a}$, 0) model. The long memory property

Figure 4 Correlograms of Standardized Residuals from MA(1)-FIGARCH (1, d, 0) Model for Daily W-US$ Spot Returns



seems to have almost disappeared in the squared and absolute terms, implying that the FIGARCH model is quite successful in representing the long memory volatility process of the daily Korean won-US dollar spot returns. The estimated parameters for the model of the daily spot returns are presented in Table 1. The estimate of the long memory parameter, *ä*, for the daily data is about 0.71.[4] Table 1 also presents that the estimates of *ä* are statistically significant at the 0.01 level. The model reported in Table 1 for the currency

[4] This estimate is close to the estimate of the persistence parameter presented in Lee (2000) who used the Stochastic Volatility (SV) model.

Table 1 Estimated MA(1)-FIGARCH(1, ä, 0) Model for Daily w-$ Spot Returns

$R_t = 100.\text{Ä}\ln(S_t) = ì + å_t + è å_{t-1},$
$å_t = z_t ó_t$ where $z_{t,n}$ is i.i.d.(0, 1) process
$ó_t^2 = ù + â ó_{t-1}^2 + [1 - âL\ (1 - L)^{ä}] å_t^2$

	Whole period (10.1.' 97-12.31.' 01)	Post-crisis period (10.1.' 98-12.31.' 01)
Observations	1109	848
ì	-0.0124	-0.0151
	(0.0112)	(0.0108)
è	0.2367	0.1325
	(0.0418)	(0.0568)
ä	0.7087	0.4190
	(0.0535)	(0.0719)
ù	0.0008	0.0100
	(0.0054)	(0.0085)
â	0.4267	0.0743
	(0.0949)	(0.0841)
ln(L)	-893.835	-388.119
Skewness	0.170	-0.277
Kurtosis	4.975	4.839
$Q(20)$	20.082	29.422
$Q^2(20)$	16.501	14.469
$W_{ä=0}$	175.370	33.950

Note: ln(L) is the value of the maximized log likelihood. The $Q(20)$ and $Q^2(20)$ are the Ljung-Box test statistics at 20 degrees of freedom based on the standardized residuals and squared standardized residuals. The sample skewness and kurtosis are based on the standardized residuals. The statistic $W_{ä=0}$ is a robust Wald test for the GARCH(1, 1) model against the FIGARCH(1, ä, 1) alternative. The test statistic has an asymptotic chi squared distribution with one degree of freedom.

appears satisfactory and does not suffer from any obvious misspecifications.

Various tests for specification of the daily spot returns model were performed.[5] In particular, a robust Wald test of a stationary GARCH(1, 1)

[5] Tests of model diagnostics are performed by applying the Box-Pierce portmanteau statistic to the standardized residuals. The standard portmanteau test statistic $Qm = T\acute{O}_{j=1,m}\, r_j^2$, where rj is the j-th order sample autocorrelation from the residuals is known to have an asymptotic chi squared distribution with m-k degrees of freedom, where k is the number of parameters estimated in the conditional mean. Similar degrees of freedom adjustment are used for the portmanteau test statistic based on the squared standardized residuals when testing for omitted ARCH effects.

model under the null hypothesis versus a FIGARCH(1, ä, 0) model under the alternative hypothesis has a numerical value of 175.4, which shows a clear rejection of the null when compared with the critical values of a chi squared distribution with one degree of freedom.[6] Hence there is strong support for the existence of hyperbolic decay and persistence as opposed to the conventional exponential decay associated with the stable GARCH(1, 1) model. A sequence of diagnostic portmanteau tests on the standardized residuals and squared standardized residuals failed to detect any need to further complicate the model. This result is quite consistent with those of previous papers which have found that the FIGARCH model seems to be more appropriate to describe the volatility process of daily exchange rates than both the GARCH and IGARCH models (Baillie *et al.*, 1996; Baillie *et al.*, 2000; Baillie and Han, 2002a, b; Beine *et al.*, 2002a, b). Also, given the extreme turbulence that occurred in the market, the estimated model in table 1 has relatively little excess kurtosis in the standardized residuals, especially when compared with the recent period high frequency data presented in Andersen and Bollerslev (1997) and Baillie *et al.* (2000).

The estimated long memory parameter (δ) from the whole sample period can be compared with that of the post-crisis period, from October 1, 1998 to December 31, 2001. The result for the post-crisis period is also presented in Table 1. The estimated long memory parameter (δ) for the post-crisis period, 0.42, is smaller than that of the whole period including the crisis, implying that the long memory property in the crisis period is more persistent than in the post-crisis period.[7] It may be due to the large changes (jumps) in the

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[6] Similar robust Wald test of a IGARCH(1, 1) model under the null hypothesis versus a FIGARCH(1, ä, 0) model under the alternative hypothesis also has a numerical value of 29.7, showing a clear rejection of the null hypothesis at the critical values of a chi squared distribution with one degree of freedom. The results of the GARCH(1, 1) and the IGARCH model are also available from the author on request.

[7] The long memory parameter in the period before the crisis is also estimated using the same FIGARCH model with the daily exchange rate data of a sample period from January 1,1993 to September 30, 1997. The estimate is found to be 0.46, which is very similar to that from the post-crisis period. The detail results are available on request from the author. The long memory parameter during the crisis period (10.1.97 through 9.30.98) cannot be estimated due to the small sample size. Lee (2000) has also found the similar result that the persistence of volatility process in daily Korea won-US dollar exchange returns increased

conditional mean process of the exchange rate caused by several events during the crisis such as speculative attacks, interventions by the BOK, the change from the fixed to the floating exchange rate system or changes in interest rate.[8] Several large changes (jumps) in the conditional mean of the Korean won- US $ exchange rates can be found in Figure 1 especially during the crisis, from October, 97 to September, 98.

3. EFFECTS OF INTERVENTIONS BY THE BANK OF KOREA DURING THE CURRENCY CRISIS

3.1. Central Bank Interventions and Theoretical Mechanisms

Even though the historical origins of sterilized intervention as a policy tool are not entirely clear, one of the earliest such interventions was in the French currency market in 1924, which is sometimes referred as the "*Poincar bear squeeze.*" Recently Baillie and Han (2002a) have suggested that the intervention of the French government in 1924 appears to have been highly successful in appreciating the French franc without affecting the volatility of the currency market. In the recent post-Bretton Woods era, intervention has typically intended to move the level of a nominal exchange rate to a target level, or to "calm disorderly markets," i.e. reduce volatility. Both intentions have been articulated in the Plaza Agreement of September, 1985 and in the Louvre Accord of February, 1987. As reported by Humpage (1988, 1987), Baillie and Osterberg (1997a) and other authors, recent many studies have generally found a "leaning against the wind" phenomenon, with a central bank's buying (selling) of a currency being associated with that currency's

after the currency crisis started.

[8] Han (2002) has recently presented that the long memory property in the volatility process of the high frequency foreign exchange rates of JPY-$, CA$-$ and DM-$ seems to be reduced significantly after the jumps in the conditional mean process are properly accounted for by the jump diffusion model. Similarly Kramer *et al.* (2002) have found that the long memory in squares of German stock returns disappears once shifting means are properly accounted for.

depreciating (appreciating). The policy endogeneity aspect obscures any direct relationship between the bank changing supply and demand conditions in the foreign exchange market. Also, they have found that intervention increased exchange rate volatility rather than reduced it. Thus, there has been a controversy over the effectiveness of intervention as a policy tool, whether it can achieve the policy objectives of either influencing the level of nominal exchange rates or reducing their volatility.

One of the transmission mechanisms of intervention is the portfolio balance theory motivated by mean-variance optimization. According to this theory, agents are concerned with their terminal wealth, which is composed of domestic and foreign currencies and bonds. The theory considers domestic and foreign bonds as imperfect substitutes, and assumes the absence of Ricardian equivalence. Sterilized intervention will then affect the exchange rate through agents re-adjusting their portfolios of domestic and foreign denominated bonds. This approach has been pursued by Dominguez and Frankel (1993), while critiques have been provided by Humpage (1988), Obstfeld (1989) and Ghosh (1992).

Another mechanism is a signaling of the central bank's future monetary policy. This implies that a sterilized purchase of foreign currency is expected to lead to a depreciation of the exchange rate if the foreign currency purchase is assumed to signal a more expansionary domestic monetary policy. Kaminsky and Lewis (1996) have reported that the impact of intervention on exchange rates has sometimes been inconsistent with the implied monetary policy, while Klein and Rosengren (1991) have found no consistent relationship between intervention and monetary policy.

Baillie and Osterberg (1997b) have proposed a further transmission mechanism which is extended a model of Hodrick (1989), to a situation incorporating the effects of intervention. The model consists of a two country inter-temporal asset pricing set up, with a two country world where consumers and governments face cash in advance constraints, and the total stock of each currency is divided between private and government holdings, with each country holding foreign currency for intervention purposes. They have found empirical

evidence supporting their theory, since purchases of dollars by the Federal Reserve System were associated with excess dollar denominated returns over uncovered interest rate parity for the freely floating DM-$ and Yen-$ exchange rates. They have also found that intervention increased rather than reduced exchange rate volatility.

3.2. Effects of Interventions by the Bank of Korea during the Currency Crisis

Intervention has been used frequently by central banks of many Asian countries like Korea, Indonesia, Thailand and Malaysia, especially during the currency crisis. In particular, the Korean currency market experienced the substantial changes in the exchange rate system from the managed floating system to the freely floating system in December 1997, and the nominal exchange rate of the won against the US dollar depreciated by about 80% during the crisis which followed. As the expectations of future depreciation increased, the BOK started to intervene in the foreign exchange market in order to increase the value of the Korean won and prevent further massive depreciation. However, as Kim (2000) has pointed out, inadequate intervention was one of the critical factors which made the currency crisis in Korea worse. There has been extensive debate over the effectiveness of intervention as a policy tool during the crisis.

This section focuses on the effects of the official interventions (which are assumed to have been sterilized) conducted by the BOK during the crisis period. Since official intervention can be defined as the official purchases and sales of foreign currencies that the monetary authorities of a country undertake to influence future currency movements (Baillie *et al.*, 2000), this paper excludes other types of intervention such as domestic monetary policies and so-called "jawboning" (verbal) intervention, where the monetary authorities issue statements designed to affect the foreign exchange market. The effect of interventions of the BOK during the crisis is investigated using a generalized FIGARCH model with a dynamic dummy variable.

Since the daily official intervention data of the BOK is not available to the public, the data set has been indirectly constructed by collecting articles from the electronic database of "Dow Jones Interactive" from October 1, 1997 to September 30, 1998. The data shows that during the crisis period the BOK conducted 21 interventions, selling US$ in order to support the value of the Korean won and smooth volatility in the currency market.[9)]

In order to investigate the effects of the interventions, it is convenient to estimate the model which includes a dummy variable to account for the interventions by BOK in both the conditional mean and variance process,

$$Y_t = 100 \times \Delta \ln(S_t) = m + [\alpha_0 / (1 - \lambda_0 l)] D_t + \varepsilon_t + \theta \varepsilon_{t-1}, \tag{6}$$

$$\varepsilon_t = z_t \sigma_t, \tag{7}$$

$$\sigma_t^2 = \omega + \beta \sigma_{t-1}^2 + [\alpha_1 / (1 - \lambda_1 L)] D_t + [1 - \beta L - (1 - L)^d] \varepsilon_t^2, \tag{8}$$

where z_t is i.i.d.(0, 1), and D_t is a dummy variable which is unity when intervention is implemented and is zero otherwise. The model was again estimated by QMLE as discussed in section 2.

Table 2 reports the results for when $\alpha_1 = \theta_1 = 0$, so that only the effects on mean returns are considered. In this specification, the impact multiplier of the intervention is α_0, the total multiplier is $\alpha_0/(1 - \theta_0)$ and the mean lag is $\theta_0/(1 - \theta_0)$. The estimation model for the intervention in Table 2 indicates MA and FIGARCH parameter estimates are generally similar to those shown in Table 1. The estimated parameters α_0 and θ_0 are found to be small but significant at the conventional levels, suggesting that the central bank interventions exerted a significant impact on the conditional mean of the exchange rates. However, the model implies the impact of the interventions by the BOK resulted in an unexpected immediate depreciation (appreciation) of the Korean won (US dollar) of about 0.09% following the intervention, and a total long run depreciation of 2.75% for the interventions. The effects

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9) The intervention data from the electronic database of "Dow Jones Interactive" is available on request from the author. The general information about "Dow Jones Interactive" is provided in the Appendix.

Table 2 Estimated MA(1)-FIGARCH(1, ä, 0) Model for Daily w-$ Spot Returns with Dummy Variable in the Mean Process for the Interventions by BOK during the Crisis.

$y_t = 100 \times \text{Ä}\ln(S_t) = \text{ì} + [\text{á}_0/(1 - \text{ë}_0 L)]\, D_t + \text{å}_t + \text{è}\text{å}_{t-1}$

$\text{å}_t = z_t\, \text{ó}_t$ where $z_{t,n}$ is i.i.d.(0, 1) process

$\text{ó}_t^2 = \text{ù} + \text{â}\text{ó}_{t-1}^2 + [1 - \text{â}L - (1 - L)^{\text{ä}}]\text{å}_t^2$

where t = 1,...1174 and D_t is one on intervention and zero otherwise.

Parameter	Estimated value
ì	-0.0142
	(0.0111)
á_0	0.0854
	(0.0420)
ë_0	0.9697
	(0.0164)
è	0.2270
	(0.0426)
ä	0.7051
	(0.0519)
ù	0.0036
	(0.0052)
â	0.3721
	(0.1068)
ln(L)	-886.833
Skewness	0.019
Kurtosis	4.731
Q(20)	14.885
Q^2(20)	14.154

Note: ln(L) is the value of the maximized log likelihood. The Q(20) and Q^2(20) are the Ljung-Box test statistics at 20 degrees of freedom based on the standardized residuals and squared standardized residuals. The sample skewness and kurtosis are based on the standardized residuals.

lasted about 1.5days on average. This result quantifies the duration of the effectiveness of the interventions by the Bank of Korea on the foreign exchange market. The unexpected result seems to be similar to that of the well known "leaning against the wind" phenomenon which has been presented by many previous empirical studies (Amekinders and Eijffinger, 1993; Baillie and Osterberg, 1997a).

One possible interpretation for the result is the policy endogeneity issue, in which interventions in foreign exchange market are decided endogenously depending on the conditions in currency markets and the movement of the exchange rate itself. In particular, Baillie and Osterberg (1997a) have presented that the deviation of US dollar exchange rates from some target rate level causes interventions, implying that central banks sell dollars when the dollars appreciates from the target level and buy them in the opposite case.[10] An alternative interpretation is the behavior of the market participants testing the resolve of central banks to intervene. Beine *et al.* (2002a) have presented that even though the initial effect of the intervention may be successful in appreciating the domestic currency during the first several hours, the market participants can further attack the currency to test the central bank's willingness to defend the currency, which can cause the currency to depreciate by the end of the trading day. Thus, as the central bank keeps on defending the currency and exhibit some resolve to intervene, the market participants should get the expected effect on the exchange rate and thus the adverse effect (a positive sign) the day after. As high frequency foreign exchange rate data has become available recently, it seems to be interesting to investigate the effects of interventions on the high frequency basis. But, it would be left for future researches.

Table 3 shows the corresponding effects of the dynamic intervention variable on the conditional variance process. While the estimated $\acute{a}_0$ and $\ddot{e}_0$

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[10] In order to examine the policy endogeneity issue, a probit model is used since the intervention data often take zero value. The estimated probit intervention model is the following;

$$I_t = \underset{(0.097)}{0.492} - \underset{(0.005)}{0.021}\,(S_t - S^*_t) + \underset{(0.006)}{0.005}\,(s_t^2 - \sigma^2) + \underset{(0.058)}{0.414}\,(I_{t-1})$$

where $(S_t - S^*_t)$ is deviation of the exchange rate (S_t) from the "target exchange rate" (S^*_t) calculated from the PPP exchange rates reflecting the BOK's concern for international competitiveness of its products, $(s_t^2 - s^2)$ is the deviation of the current volatility from the average volatility (s^2) which is the unconditional variance, and I_{t-1} is the lagged intervention. The results support the "leaning against the wind" effect even in the short run. The results show that the BOK intervened when the exchange rates wandered from the target value and is likely to intervene if it intervened on the previous day while the interventions seem not to have been induced by the market volatility. These results seem to be in accord with Rhee and Song (1999).

parameters for the conditional mean process are found to be significant at the conventional level as in Table 2, the estimated $\acute{a}_1$ and $\ddot{e}_1$ parameters for the conditional variance process are found to be insignificant, implying that there is not statistically significant evidence that the BOK interventions affected trading activity or market volatility. This is in accord with the result of Baillie and Han (2002a) which tested the intervention of French government in the currency markets in 1920s, while contrasting with the results reported by Chang and Taylor (1998), Baillie and Osterberg (1997a, b), Goodhart and Hesse (1993) and Beine *et al.* (2002a), who all noted increases in volatility following interventions. Also, the estimated long memory parameter (d) is found to be almost the same as that of the model without the dummy variable. Thus, the long memory property of the volatility process appears not to be affected by central bank interventions.

Many theories of intervention in the post-Bretton Woods period have emphasized the effect of intervention on deviations from UIP (uncovered interest rate parity), rather than a direct effect on the spot rate. The portfolio balance model of Dominguez and Frankel (1993) and the risk premium model of Baillie and Osterberg (1997b), who extended the model of Hodrick (1989), implies that intervention affects the risk premium term, $\tilde{n}_t$, in the model

$$(s_{t+k} - s_t) - (f_t - s_t) = (s_{t+k} - f_t) = \sum_{j=l,k} \boldsymbol{q}_j \boldsymbol{e}_{t-j} + \boldsymbol{r}_t, \qquad (9)$$

where f_t is the logarithm of the forward exchange rate for a k period maturity time. Hence the left hand side of equation (9) is the forward rate forecast error, $(s_{t+k} - f_t)$, and the first term on the right hand side of the equation is a MA(k) process to reflect the fact that the forward rate forecast error may be autocorrelated to lag k, while $\tilde{n}_t$ is the risk premium and $\mathring{a}_t$ is a white noise process with zero mean, finite variance and is also serially uncorrelated.

For the estimation of equation (9), the daily 1-month non-deliverable forward (NDF) exchange rates[11)] are used to generate the forward forecast

[11)] The 1-month non-deliverable forward (NDF) exchange rate data is kindly provided by Prebon Yamine (HK) Ltd.

Table 3 Estimated MA(1)-FIGARCH(1, *ä*, 0) Model for Daily w-$ Spot Returns with the Dummy Variables in the Mean Process and the Variance Process for the Interventions by BOK during the Crisis

$y_t = ì + [á_0 /(1 - ë_0 L)] D_t + å_t + è å_{t-1}$

$å_t = z_t ó_t$ where $z_{t,n}$ is i.i.d.(0, 1) process

$ó_t^2 = ù + [á_1 /(1 - ë_1 L)] D_t + â ó_{t-1}^2 + [1 - âL - (1 - L)^ä] å_t^2$

where t = 1,...1174 and D_t is one on intervention and zero otherwise

Parameter	Estimated value
$ì$	-0.0142
	(0.0110)
$á_0$	0.0727
	(0.0284)
$ë_0$	0.9661
	(0.0161)
$è$	0.2110
	(0.0394)
$ä$	0.7137
	(0.0571)
$ù$	0.0042
	(0.0053)
$á_1$	0.0507
	(0.0381)
$ë_1$	0.9952
	(0.0115)
$â$	0.3754
	(0.1184)
ln(L)	-881.738
Skewness	-0.007
Kurtosis	4.715
Q(20)	16.183
Q^2(20)	15.214

Note: As for table 2.

error, $(s_{t+k} - f_t)$, and the average maturity time of the forward contract, k is 21 as suggested by Baillie and Osterberg (1997b). The results of QMLE of equation (9) with MA (21) process and the intervention variable, D_t, representing the risk premium term $ñ_t$, show that the coefficient of the intervention variable is not significant at the conventional level, implying that there is no evidence of intervention having a lagged effect on these excess returns. Hence there is no

statistical evidence that intervention Granger causes excess returns from uncovered interest rate parity, which contrasts with Baillie and Osterberg (1997b) who reported significant results for the DM-$ and Yen-$ in the post Bretton Woods era. Thus, the interventions by the BOK seem to have a different transmission mechanism during the crisis compared with in the post Bretton Woods era, albeit with a direct effect on the spot market in the unexpected direction. The detailed results are not reported to reserve the space, but they are available on request from the author.

4. CONCLUSION

This paper has examined the characteristics of the Korean won-US dollar daily exchange rates and the effects of the BOK interventions in the foreign exchange market. The spot exchange returns exhibit the long memory properties in their absolute returns and conditional variances, which is the well documented feature of the foreign exchange market. The long memory volatility process, FIGARCH model is found to be an appropriate description of the volatility process of the daily won-dollar returns. The estimated long memory parameter is found to be more persistent during the crisis.

Most central banks rely on intervention activity, believing that such activity is effective in either influencing the level of exchange rates or in reducing the volatility of the market. This paper has investigated the effectiveness of interventions conducted by the BOK which intended to achieve the two objectives: to support the Korean won and to make the disorderly market calmer during the currency crisis. This paper uses a generalized FIGARCH model including a dynamic dummy variable to account for the interventions. The results show that the interventions can affect the level of the won-$ exchange rate significantly, but in the opposite direction, which is similar to the usual "leaning against the wind" phenomenon. The interventions of the BOK are estimated to have led to an immediate depreciation of the Korean won by 0.09%, and a total long run appreciation of 2.8%. But the model

reveals that the intervention had no effect on market volatility. Thus, this paper provides some statistical evidence that the interventions of the BOK during the crisis seem to be unsuccessful in curtailing further depreciation of the Korean won–US dollar exchange rates. Also, this paper has found that the interventions had no impacts on the risk premium or excess returns over uncovered interest rate parity (UIP).

APPENDIX

Electronic Database of "Dow Jones Interactive"

The electronic database of "Dow Jones Interactive" is a vast archive of the world's most important publications, reports and news. It includes current and most recent back issues of the world's leading newspapers and selected business magazines, articles on any subject in the full text of more than 6,000 leading business newspapers, magazines, trade journals and newsletters and television and radio transcripts and the latest news on any subject delivered automatically to folders you set up in Dow Jones Interactive. Dow Jones Interactive also provides links to these other Dow Jones products such as the Wall Street Journal Interactive Edition for the link to the Interactive Journal to get the day's in-depth business news, as well as Current Futures, Futures, Options and Global Index Data and Dow Jones Web Center for search the public Web for relevant and timely business news and information. Dow Jones editors identify and select only the top news and business Web sites (over 1,200) for inclusion, and update each site one to four times daily. This database provides the detailed information for the interventions by the BOK with specifying the time and the amounts. The database is provided by City University of Hong Kong.

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