Quantitative Comparisons on the Intrinsic Features of the daily USD-GBP Exchange Rates: the 1920s vs. the 2010s*

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Abstract

This paper quantitatively compares the intrinsic features of the daily USD-GBP exchange rates in two different periods, the 1920s and the 2010s, under the same flexible exchange rate system. Even though the foreign exchange markets in the 1920s seem to be much less organized and developed than in the 2010s, both the long memory property and the structural break appear to be the key intrigue features of the exchange rates and the long memory volatility property is commonly found to be upward biased and overstated due to the structural breaks in the two periods. In particular, this paper finds that the long memory volatility property in the 1920s is much greater than in the 2010s, which is closely related to the structural breaks in the exchange markets by using the standard FIGARCH model. Then this paper applies the Adaptive-FIGARCH model to consider the long memory property and the structural breaks jointly. The main finding is that the structural breaks in the exchange markets affect the long memory volatility property significantly in the both periods but the degree of the long memory volatility property in the 1920s is reduced more remarkably than in the 2010s after the structural breaks are accounted for implying that the structural breaks in the foreign exchange markets in the 1920s seem to be more significant.

Key words: the 1920s, daily USD-GBP exchange rates, long memory volatility property, structural breaks, FIGARCH model, Adaptive FIGARCH model.

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I. Introduction

As pointed by Baillie and Bailey (1984), many economists have been fascinated for a long time with the floating exchange rates that occurred in the 1920s. In this context, the floating exchange rate in the 1920s is worthy of study because it provides an opportunity to collaborate evidence from the current floating rates in the 2010s. In particular, the currency market in the early 1920s experienced one of the most turbulent periods in the history of foreign exchange markets as the markets adjusted to post WWI and non-Gold standard conditions. Problems associated with the hyperinflation in Germany and budget deficit in France spilled over to affect several neighboring currencies. Einzig (1937, 1962) has documented many of the main economic and political events of this period and their impact on the currency markets. Thus, the period of the 1920s is a very interesting period of history since it is one of the earliest periods of widespread freely floating exchange rates that was remarkable for their great turbulences due to the political and economic conditions in Europe and it constitutes the other main source of information on the behavior of the floating exchange rates with being well documented from a data perspective (e.g. Matthews, 1986; Taylor and McMahon, 1988; Smith and Smith, 1990; Taylor, 1992; Baillie *et al*., 1993).

The exchange markets in the 1920s seem to be very different from those in the 2010s in several aspects. Although relatively little precise information is known about the extent of capital movements in the 1920s markets, it seems that there was a very low level of capital movements and arbitrage. Hence, the total volume of foreign exchange market transactions would be only marginally more than the volume of trade. And, the exchange markets in the 1920s were clearly less well organized and developed, and they were in the less sophisticated telecommunications system compared with them in the 2010s which have more innovative market structures with more advanced computer technology and better developed financial instruments like options and futures. These facts distinguish the 1920s from the 2010s era.

Despite the relatively primitive market conditions, the 1920s foreign exchange markets seem to be similar in character to current markets in the 2010s in terms of the world economic situations. The world economy in the 1920s was recovering from the devastating effects of the WWI with the turmoil of war reparations and hyperinflation in Germany (Baillie *et al*., 1993). This also led to concerted speculative attacks on various currencies. These situations in the 1920s are quite similar to the happenings in the 2010s in which most of exchange rates change very volatilely in foreign exchange markets with frequent speculations on currencies and the world economy is overcoming the global financial crisis with a worldwide credit crunch resulted from the collapse of the US subprime mortgage industry in 2007 (Melvin and Taylor, 2009).

Hence, the main purpose of this paper is to quantitatively compare the intrinsic features of the exchange rates in the 2010s with those in the 1920s. For the comparison, this paper focuses on the two key features, long memory volatility property and structural breaks of exchange rate returns in the periods of the 1920s and the 2010s. In particular, this paper uses the daily exchange rates of US Dollar (USD)-Great British Pound (GBP) which is globally traded in the both periods and investigates the dynamics of the long memory volatility property and the structural breaks in the daily exchange returns. This analysis seems warranted for the reason that this issue has not been previously investigated and it is useful to add to the stock of empirical comparison studies.

The quantitative comparison in this paper finds that the daily USD-GBP exchange returns in the 1920s contain surprisingly similar intrinsic features to those in the 2010s in terms of the long memory volatility property and the structural breaks. First, the extreme turbulence in the markets is seen to induce the heavy tailed variance of unconditional returns in both the 1920s and the 2010s as studied by Koedijk*et al*. (1990). In particular, the daily USD-GBP exchange returns in the 1920s are found to exhibit the widespread long memory property in the volatility process of the exchange returns with quite persistent and hyperbolic decaying autocorrelations, which is extremely similar to them in the 2010s. In order to estimate the degree of the long memory volatility property of the exchange returns, this papers uses the FIGARH model of Baillie *et al*. (1996) as well as the GARCH model of Bollerslev (1986) for the comparison. The magnitude of the long memory volatility property in the daily USD-GBP exchange returns in the 1920s appears to be much greater than that in the 2010s.

Second, this paper finds that there exist several structural breaks in the daily USD-GBP exchange returns in the both periods of the 1920s and 2010s which appear to be closely related to the long memory volatility property (Granger and Terasvirta, 1999; Diebold and Inoue, 2001). In particular, the exchange returns in the 1920s is found to contain the more significant structural breaks than in the 2010s, which implies that the structural breaks occurred more frequently in the foreign exchange markets in the 1920s seem to affect the long memory volatility property in the 1920s more significantly than in the 2010s. Thus the greater long memory volatility property in the exchange returns in the 1920s could be due to the more frequent structural breaks in the exchange markets in the 1920s.

In this context, this paper examines the two features, the structural breaks and the long memory property together in the volatility process of the daily USD-GBP exchange returns by applying the Adaptive FIGARCH (A-FIGARCH) model of Baillie and Morana (2009) with the Adaptive GARCH (A-GARCH) model for the comparison. The adaptive-(FI)GARCH model augments the standard (FI)GARCH model with a deterministic component following Gallant (1984)'s flexible function form. Thus the A-(FI)GARCH model appears quite useful in analyzing the volatility process of the daily exchange returns by allowing for both the stochastic long memory component and the deterministic structural break component. And, the A-(FI)GARCH model has an advantage of being computationally straightforward since the model does not require pre-testing for the numbers of structural break points nor does it require any smooth transition between volatility regimes.

This paper finds that the A-(FI)GARCH model outperforms the standard (FI)GARCH model in the estimation of the long memory property in the both periods when the structural breaks are present. As in the A-GARCH model, the degree of the long memory property in the volatility process of the daily returns is reduced in both cases after the structural breaks are accounted for in the A-FIGARCH model indicating that the structural break is another key intrigue feature of the exchange returns in both periods and that the part of the observed long memory property in the volatility process of the daily exchange returns in both cases could be upward biased and overstated by the structural breaks. In particular, the long memory volatility property in the 1920s is reduced more remarkably suggesting that the long memory property in the 1920 appears to be mostly a spurious feature due to the more significant structural breaks in the exchange markets in the 1920s.

The rest of this paper is organized as follows. Section 2 presents the descriptive statistics of the daily USD-GBP exchange returns in the periods of the 1920s and the 2010s and provides the results from the estimation of the usual FIGARCH model as well as the GARCH model for the comparison in order to represent the long memory volatility property in the exchange returns. Section 3 reports the estimation results of the A-FIGARCH model to account for the structural breaks and the long memory property jointly in the volatility process of the exchange returns together with the results of the A-GARCH model for the comparison. Then section 4 concludes briefly.

II. Descriptive Statistics and Long Memory Volatility Property

1) Descriptive Statistics

Before embarking on the formal econometric analysis, it is worthwhile examining the general patterns of the USD-GBP exchange rates under consideration. For the purpose, this section is concerned with the basic descriptive statistics and the long memory volatility property in the daily USD-GBP exchange rates in the periods of the 1920s and the 2010s. For the primary dataset in the 1902s, this paper uses the daily exchange rate data originally collected from *Manchester Guardian* newspapers for the London market with sampling from May 1, 1922 through May 30, 1925.[1)] Since the market was open on Saturdays, there are six observations per week and hence a total of 966 observations for this sample period. And, the dataset in the 2010s are obtained from the Olsen and Associates with the sample period of May 3, 2010 through May 31, 2013, which is almost the same period as the 1920s data. In particular, the each quotation of the 2010s data consists of a bid and an ask price 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. The weekend data with much lower trading activities are excluded resulting in five observations per a week since they cannot provide any economic implications (Bollerslev and Domowitz, 1993). Thus, the exchange rates realize a sample of total 805 observations for the 2010s data.

The time series realizations of the daily USD-GBP exchange rates in the 1920s and the 2010s are plotted in Figures 1(a) and (b) respectively. In particular, the movements of the exchange rates in the 1920s appear to be more abrupt with several significant structural breaks in the market than them in the 2010s. The GBP had become increasingly appreciated against USD during the periods of 1921 and 1922 and the periods of early 1924 and mid-1925. In particular, the UK monetary authorities were actively engaged in a return to gold policy given that in the latter part of this sample period (Taylor, 1992). But the GBP was depreciated steeply against the USD after October 1923 when the British government urged more expansionary fiscal and

[1)]. Phillips *et al*. (1996) has used the same data to test whether the forward rate is an unbiased predictor of the future spot rate monetary policies to meet growing unemployment, caused a flight of capital from UK and more turbulence in the foreign exchange market (Aliber, 1962; Baillie and Bailey, 1984). Also, the returns of the daily exchange rates are defined in the conventional manner as continuously compounded rates of return and calculated as the first difference of the natural logarithm of prices. In Figure 2(a) and (b), both returns are centered on zero and there exist obvious volatility clustering. But more extreme turbulences at the 1920s markets are seen to induce much heavier tailed, undefined variance of unconditional returns phenomenon (Koedijk *et al*., 1990) compared with the 2010s markets.

In Figure 3 (a) and (b) which present the autocorrelation function of the returns, squared returns and absolute returns of the daily USD-GBP exchange rates in the 1920s and the 2010s, the first order autocorrelations in the two returns are all small while higher order autocorrelations of the two raw returns are not significant at conventional significance levels. However, the autocorrelations of the squared returns and the absolute returns for the two exchange rates decay very slowly at the hyperbolic rate, which is typical of freely floating nominal spot exchange rates and the feature of the long memory property. This long memory volatility property is very significant in the autocorrelations of the squared and absolute returns of the two daily USD-GBP exchange rates in the 1920s and the 2010s and is more apparent in the autocorrelation functions of the absolute returns as presented by Granger and Ding (1996). And, the degree of the long memory volatility property seems to be more significant in the 1920s than in the 2010s.

The details of the descriptive statistics for the two daily USD-GBP returns in the 1920s and the 2010s are provided in Table 1. The sample means of the daily returns in the 1920s and the 2010s are found to be 0.0097 and -0.0005 respectively, which are very close to zero and indistinguishable at the standard significance level given the sample deviations of 0.227 and 0.520. In particular, the daily returns in the 1920s appear not to be normally distributed since the value of the skewness is 0.82 and the value of the kurtosis is 9.47, which are greater than the levels of the normal distribution, and they are all statistically significant.[2)] The more substantial excess kurtosis in the 1920s is consistent with the more systematic occurrence of tranquil and volatile periods than in the 2010s as presented in Figures 1 and 2. And, the Ljung-Box test statistics for the test of the serial correlations, $Q^2(20)$, calculated from the squared returns in the

[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 $(24/T)^{1/2}$.

1920s and the 2010s are 152.41 and 51.76, which are statistically significant indicating the existence of highly persistent autocorrelations in the conditional variance process. The serial correlation seems to be more significant in the 1920s returns than in the 2010s returns. Thus, the conditional variance process of the returns in the 1920s appears to be more persistent than in the 2010s, which is quite consistent with the correlograms in the Figure 3. Despite the more primitive market conditions in the 1920s compared with the current markets in 2010s, the exchange returns in the 1920s appear remarkably similar pattern to the current returns in the 2010s but with more persistent volatility process.

2) Long memory volatility process

The model that is consistent with the basic stylized properties is the ARMA(*m*,*n*)-FIGARCH(*p*, *d*, *q*) process,

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

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

$$[1-\beta(L)]\sigma_t^2 = \omega + [1-\beta(L)-\phi(L)(1-L)^d]\varepsilon_t^2 \tag{3}$$

where y_t is the returns of the daily USD-GBP exchange rates, and $z_t \sim i.i.d.(0,1)$, μ and ω are scalar parameters, and $\beta(L)$ and $\phi(L)$ are polynomials in the lag operator to be defined later. The polynomials in the lag operator associated with the AR process and MA process are $\varphi(L) = 1 + \varphi_1 L + \varphi_2 L^2 + .. + \varphi_m L^m$ and $\theta(L) = 1 + \theta_1 L + \theta_2 L^2 + .. + \theta_n L^n$. And, the parameter ($d$) represents the long memory parameter. The FIGARCH model in equation (3) is motivated by noting that the standard GARCH (p, q) model of Bollerslev (1986) can be expressed as

$$\sigma_t^2 = \omega + \alpha(L)\varepsilon_t^2 + \beta(L)\sigma_t^2, \tag{4}$$

where the polynomials are $\alpha(L) \equiv \alpha_1 L + \alpha_2 L^2 + ... + \alpha_q L^q$, $\beta(L) \equiv \beta_1 L + \beta_2 L^2 + ... + \beta_p L^p$.

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, serially uncorrelated process which has the interpretation of being the innovations in the conditional variance. Similarly, the FIGARCH(p, d, q) process can be written naturally as

$$\phi(L)(1-L)^d \varepsilon_t^2 = \omega + [1-\beta(L)]\upsilon_t, \tag{5}$$

where $\phi(L) = [1 - \alpha(L) - \beta(L)]$ is a polynomial in the lag operator of order max(p, q). Equation (5) can be easily shown to transform to equation (3), which is the standard representation for the conditional variance in the FIGARCH(p, d, q) process. Further details concerning the FIGARCH process can be found in Baillie *et al*. (1996). The parameter d characterizes the long memory property of hyperbolic decay in volatility because it allows for autocorrelations decaying at a slow hyperbolic rate. For $0<d<1$, the FIGARCH model has an undefined unconditional variance implying a long memory behavior and is strictly stationary and ergodic (Baillie *et al*., 1996; Baillie and Morana, 2009), However, the process does posses 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).

When $d = 0$, $p = q = 1$, then equation (3) reduces to the standard GARCH(1,1) model; and when $d = p = q = 1$, 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, $\sigma^2_t = \omega/(1 - \beta) + \lambda(L)\varepsilon^2_t$, where $\lambda_k \approx k^{d-1}$, which is essentially the long memory property, or "Hurst effect" of hyperbolic decay. The attraction of the FIGARCH process is that for $0 < d < 1$, it is sufficiently flexible to allow for intermediate ranges of persistence. Analogous behavior in the conditional mean of exchange rates has been considered by Cheung (1993). The simpler FIGARCH(1,d,0) process is of the form, $\sigma^2_t = \omega + \beta\sigma^2_{t-1} + [1 - \beta L - (1 - L)^d]\varepsilon^2_t$, and has corresponding impulse response weights, $\sigma^2_t = \omega/(1 - \beta) + \lambda(L)\varepsilon^2_t$; and for large lag k, $\lambda_k \approx [(1-\beta)/\Gamma(d)]k^{d-1}$.

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

$$\ln(L;\Theta) = -(\frac{T}{2})\ln(2\pi) - (\frac{1}{2})\sum_{t=1}^{T}[\ln(\sigma_t^2) + \varepsilon_t^2\sigma_t^{-2})] \tag{6}$$

where Θ is a vector containing the unknown parameters to be estimated. However, it has long been recognized that most asset returns are not well represented by assuming z_t in equation (2) is normally distributed; for example see McFarland *et al*.(1982). And, 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 by Baillie and Morana (2009). Thus, the inference is usually based on the QMLE of Bollerslev and Wooldridge (1992), which is valid when z_t is non-Gaussian. Denoting the vector of parameter estimates obtained from maximizing (6) using a sample of T observations on equations (1), (2) and (3) with z_t being non-normal by $\hat{\Theta}_T$, then the limiting distribution of $\hat{\Theta}_T$ is

$$T^{1/2}(\hat{\Theta}_T - \Theta_0) \rightarrow N[0, A(\Theta_0)^{-1} B(\Theta_0) A(\Theta_0)^{-1}], \qquad (7)$$

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

Equation (7) 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.

This section of the paper represents an extensive analysis of the volatility properties of the two USD-GBP returns in the 1920s and the 2010s using the FIGARCH model of Baillie *et al.* (1996) and the GARCH model of Bollerslev (1986) for the comparison. The orders of the ARMA and GARCH polynomials in the lag operator are chosen to be as parsimonious as possible but still provide an adequate representation of the autocorrelation structure of the daily exchange returns data. The exact parametric specification of the model that best represents the degree of autocorrelation in the conditional mean and conditional variance of the daily returns are found to be the MA(1)-FIGARCH(1, d, 0) model and MA(1)-GARCH(1,1) model.

Estimation results are reported in Table 2 applying the above models for the USD-GBP returns in the 1920s and the 2010s. In the case of the GARCH model, the sum of the estimated values of the volatility persistence parameters (β and φ) in the GARCH model is equally found to almost close to 1, implying the complete persistence of the IGARCH model. A consequence of neglecting structural breaks is that the GARCH model tends to produce results consistent with the data being generated by an IGARCH process. But, the GRACH model may not provide any difference in the persistence of the volatility process of the daily returns in the two different periods.

However, the estimation result of the FIGARCH model which accounts for the long memory property shows that the long memory parameters (d) in the volatility process of the daily returns are estimated to be0.86 and 0.21 for the 1920s and the 2010s returns and they are all the statistically significant at the conventional level implying that the degree of the persistence in the volatility process of the two returns are quite different depending on the periods. It presents strong support that there exists the significant long memory property in the volatility process of the daily USD-GBP returns for the two periods and that the long memory volatility property in the 1920s appears to be much greater than that in the 2010s. This result confirms the fact represented in Figure 3 which shows the apparent autocorrelations decaying more slowly at the hyperbolic rate in the squared and the absolute returns in the 1920s than those in the 2010s. As some papers show that the time series with structural breaks can induce a strong persistence in the autocorrelations (Diebold and Inoue, 2001; Granger and Hyung, 2004; Perrron and Qu, 2006), the more significant long memory volatility property in the 1920s could be closely related to the more apparent and frequent structural breaks in the 1920s exchange markets presented in Figures 1 and 2. Thus, the long memory volatility property is one of key intrigue features in the daily USD-GBP returns for the 1920s and the 2010s, but it is much more significant in the 1920s than in 2010s.

Based on the robust Wald test of the stationary GARCH(1,1) null hypothesis versus a FIGARCH(1,d,0) alternative being overwhelmingly rejected, the FIGARCH model which accounts for the long memory property generally yields an improvement in specification in the all cases considered for the GARCH model. And, the estimated values of the Q(20) and the $Q^2(20)$ which are the Ljung-Box test statistics show that the FIGARCH model specified for the daily returns performs a good job of capturing the autocorrelations in the conditional mean and the conditional variance of the daily USD-GBP 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.[3)] Thus, the FIGARCH model matches the long memory volatility property of the daily USD-GBP returns in the 1920s and the 2010s more appropriately than the GARCH model. This finding is consistent with the papers of Andersen *et al*. (2003) and Bhardwaj and Swanson (2006) in the fact that the long memory process model provide significantly better out of sample prediction than the GARCH model.

[3)] Tests of model diagnostics are performed by the application of the Box-Pierce portmanteau statistic on the standardized residuals. The standard portmanteau test statistic $Q_m = T\Sigma_{j=1,m}\, r_j^2$, where r_j 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. This adjustment is in the spirit of the suggestions by Diebold (1988).

III. Long memory volatility property and structural breaks

This section considers the relation of the structural breaks with the long memory volatility property in the daily USD-GBP exchange returns by applying the Adaptive FIGARCH (A-FIGARCH) model of Baillie and Morana (2009).[4)] As presented in the introduction, many previous studies have provided abundant motivations to allow for the possibility of the structural breaks in the volatility process of financial time series data including foreign exchange rates. 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 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 Gallant (1984) flexible functional form. In particular the flexible functional form of Gallant (1984) can allow for a very efficient modeling of structural breaks without requiring any pretests to determine the actual location of break points and adding estimation complexity. Thus, 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. And, one of the great advantages of this model is the simplicity of computation adding no additional burden to the estimation of the usual FIGARCH model. Moreover, Baillie and Morana (2009) have found that the A-FIGARCH model shows a superior performance relatively to the usual FIGARCH model in terms of bias and root mean square error (RMSE).

In this context, this paper adopts the A-FIGARCH model together with the A-GARCH model for the comparison in order to account for jointly the long memory volatility property and the structural breaks in the daily returns. While the mean process of the daily returns is still specified as following an MA(1) process as in Section II, the volatility process is represented by the A-FIGARCH (1,d,0,k) model with the trigonometric term (k) for the Gallant's 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;

$$y_t = \mu + \theta\varepsilon_{t-1} + \varepsilon_t \tag{8}$$

$$\varepsilon_t^2 = z_t\sigma_{t,} \tag{9}$$

4) There are different types of 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).

$$(1-\beta L)\sigma_t^2 = \omega_t + [1-\beta L-(1-L)^d]\,\varepsilon_t^2 \qquad (10)$$

$$\omega_t = \omega_0 + \sum_{j=1}^{k}[\gamma_j \sin(2\pi jt/T) + \delta_j \cos(2\pi jt/T)] \qquad (11)$$

And, the Gaussian loglikelihood function of the model is the same as the MA(1)-FIGARCH(1,d,0) model in Section II. Also, 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. One important consideration is the determination of the trigonometric terms (k) in the Gallant flexible functional form for the practical implementation of the model. In this paper, the trigonometric terms (k) are selected 9 for the 1920s returns and 2 for the 2010s returns based on the Akaike Information criterion (AIC) and the Schwartz Information criterion (SIC).

The estimation results of the above model for the daily USD-GBP exchange returns are reported in Table 3. Once the structural breaks and the long memory volatility property are jointly modeled, an improvement in fit can be noted as well as a reduction in the long memory parameter indicating the structural break is also one key intrigue feature of the daily returns in the two periods. In particular, the estimated parameters of the long memory volatility property in the daily returns are found to be 0.008 and 0.162 for the 1920s and the 2010s returns, and they are all statistically significant. As already found in the A-GARCH model, it can be noted that an upward and overstated bias in the long memory property is imparted by neglecting the structural breaks in both cases by comparing the estimated long memory parameters. This finding is in line with Choi and Zivot (2006) in which allowing for structural breaks reduces the persistence but there is still evidence of the long memory property in the forward discount series. Thus, the long memory volatility and the structural breaks could be the key intrigue features of the exchange returns in the both cases.

The long memory property in the 2010s returns is still strong even after the structural breaks are eliminated suggesting that the long memory property in the 2010s returns appears to be a truly intrigue feature in the exchange markets. But, the long memory property in the 1920s returns is found to be reduced more significantly and quite small when the structural breaks are accounted for. This result indicates that the 1920s returns with the significant structural breaks may induce a strong persistence in the volatility process and hence the long memory property seems to be a spurious feature (Diebold and Inoue, 2001; Granger and Hyung, 2004; Perron and Qu; 2006). This may be because the long memory volatility property of the exchange returns in the 1920s could be easily confused with the structural breaks in foreign exchange markets so that it may be very difficult to distinguish between the intrigue and the spurious long memory property as pointed by Shimotsu (2006) in which the long memory property and the structural breaks are almost observationally equivalent so that the long memory may fall into an "empty box" category.

In addition, the robust Wald test statistics of the FIGARCH null hypothesis versus the Adaptive-FIGARCH alternative support the facts that the inclusion of the trigonometric components makes an important improvement to the general goodness of fit of the model and that the A-FIGARCH is superior to FIGARCH when the structural breaks are presented, which is consistent with the findings of Baillie and Morana (2009). Thus, this paper can find the improvement in specification fit and the reduction in the long memory parameter once the structural breaks and the long memory property are jointly modeled.

IV. Conclusion

The period of the 1920s is a very interesting period of history and the floating exchange rate in the 1920s is worthy of study because it provides an opportunity to collaborate evidence from the current floating rates in the 2010s, and it constitutes the other main source of information on the behavior of the floating exchange rates. And, the 1920s foreign exchange markets with the relatively primitive market conditions are found to be quite similar to the markets in the 2010s. Hence, this paper quantitatively compares the intrigue features of the daily USD-GBP exchange rates in the 1920s with them in the 2010s. Special attention is devoted to account for both the structural breaks and the long memory volatility property of the daily exchange returns in both periods.

This paper first uses the standard FIGARCH model of Baillie *et al*. (1996) with the GARCH model of Bollerslev (1986) for the comparison in order to figure out the long memory volatility property of the daily returns series in the periods of the 1920s and the 2010s. This paper finds strong evidence for the hyperbolic decay and significant persistence of the autocorrelations in the volatility process of the daily returns in the two periods, which is the typical feature of the long memory property. Thus, the long memory volatility property is found to be one of key intrigue features in the volatility process of the daily returns in the two periods. And, the standard FIGARCH model is found to provide an adequate fit and match the dynamics of the daily returns in the two periods. In particular, the long memory volatility property in the 1920s returns appears to be much greater than that in the2010s returns, which could be closely related to the significant structural breaks in foreign exchange markets in the 1920s.

Following many previous studies which have allowed for the possibility of the structural breaks in the volatility process of financial time series data including foreign exchange rates, this paper then applies the Adaptive-FIGARCH (A-FIGARCH) model of Baillie and Morana (2009) with the Adaptive-GARCH (A-GARCH) model for the comparison which is designed to model the structural beaks and the long memory property jointly in the volatility process of the daily exchange returns in the two periods. Main finding of this paper is that the A-FIGARCH model outperforms the standard 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 volatility 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 and overstated long memory property in the volatility process of the daily returns in the two periods could be imparted by neglecting the structural breaks, indicating that both the long memory volatility property and the structural breaks are the key intrigue features of the daily returns in the two periods. In particular, the long memory property in the 1920s returns is found to be quite small when the structural breaks are accounted for in the specification model. This result implies that the significant structural breaks in the foreign exchange markets in the 1920s may induce a strong persistence in the volatility process of the daily returns and hence produce the more significant long memory property.

References

Aliber, R.Z. 1962. Speculation in the foreign exchanges: the European experience, 1919-1926. *Yale Economic Essays* **2**: 171-245.

Andersen, T.G., Bollerslev, T., Diebold, F.X. and Labys, P. 2003. Modeling and forecasting realized volatility. *Econometrica* **71**: 579-625.

Baillie, R. T. 1996. Long memory processes and fractional integration in econometrics. *Journal of Econometrics* **73**: 5-59.

Baillie, R.T. and Bailey , R.W. 1984.International currency speculation, markt stability and efficiency in the 1920s: a time series approach. *Journal of Macroeconomics* 6:127-137.

Baillie, R.T., Bollerslev, T. and Mikkelsen, H.-O. 1996. Fractionally integrated generalized autoregressive conditional heteroscedasticity. *Journal of Econometrics* **74**: 3-30.

Baillie, R.T., Bollerslev, T. and Redfearn, R.M. 1993. Bear squeezes, volatility spillovers and speculative attacks in the hyperinflation 1920s foreign exchange. *Journal of International Money and Finance* **12**: 511-521.

Baillie, R.T., Cecen, A.A. and Han, Y.W. 2000. High frequency Deutsche mark-US Dollar returns; FIGARCH representations and non-linearities. *Multinational Finance Journal* **4**: 247-267.

Baillie, R.T., Cecen, A.A., Erkal, C. and Han, Y.W. 2004. Merging the Stochastic with the Nonlinear Deterministic: the Case of High Frequency European Exchange Rates. *Journal of International Financial Markets, Institutions & Money* **14**: 401-418.

Baillie, R.T. and Morana, C. 2009. Modeling long memory and structural breaks in conditional variances: an Adaptive FIGARCH approach. *Journal of Economic Dynamics & Control* **33**:1577-1592.

Bjardwaj, G. and Swanson, N.R. 2006. An empirical investigation of the usefulness of ARFIMA models for predicting macroeconomic and financial time series. *Journal of Econometrics* **131**: 539-578.

Bollerslev, T. 1986. Generalized autoregressive conditional heteroscedasticity. *Journal of Econometrics* **31:** 307-327.

Bollerslev, T. and Domowitz, I. 1993. Trading patterns and prices in the interbank foreign exchange market. *Journal of Finance* **48**: 1421-43.

Bollerslev, T. and Wooldridge, J.M. 1992. Quasi-maximum likelihood estimation of dynamic models with time varying covariances. *Econometric Reviews* **11**: 143-172.

Cheung, Y.-W. 1993. Long memory in foreign exchange rates. *Journal of Business and Economic Statistics* **11:** 93-101.

Choi, K. and Zivot, E. 2007. Long memory and structural changes in the forward discount: An empirical investigation', *Journal of International Money and Finance* **26**: 342-363.

Diebold, F.X. 1988. *Empirical Modeling of Exchange Rate Dynamics.* New York: Springer Verlag.

Diebold, F. X. and Inoue, A. 2001. Long memory and regime switching. *Journal of Econometrics* **105**: 131-159.

Einzig, P. 1937. *The Theory of Forward Exchange*. London, MacMillan.

Einzig, P. 1962. *The History of Foreign Exchange*. New York, St. Martin's Press.

Engle, R.F. and Rangel, J.G. 2008. The spine-GARCH model for low frequency volatility and its global macroeconomic causes. *Review of Financial Studies* **21**: 1187-1222.

Gallant, A. R. 1984. The fourier flexible form. *American Journal of Agricultural Economics* 66: 204-208.

Granger, C.W.J. and Ding, Z. 1996. Modeling volatility persistence of speculative returns. *Journal of Econometrics* **73**: 185-215.

Granger, C.W.J. and Hyung, N. 2004. Occasional structural breaks and long memory with an application to the S&P500 absolute stock returns. *Journal of Empirical Finance* **11**: 399-421.

Granger, C.W.J. and Terasvirta, T. 1990. A nonlinear time series model with misleading linear properties. *Economic Letters* 62: 161-165.

Jarque, C. M. and Bera, A.K. 1987. Test for normality of observations and regression residuals. *International Statistical Review* **55**: 163-172.

Karanassos, M., Psaradakis, Z. and Sola, M. 2004. On the autocorrelation properties of long memory GARCH process. *Journal of Time Series Analysis* **25**: 265-281.

Koedijk, K.G., Schafgens, M.M.A. and de Vries, C.G. 1990. The tail index of exchange rate returns. *Journal of International Economics* **29**: 93-108.

Matthews, K.G.P. 1986. Was sterling overvalued in 1925?. *Economic History Review* **39**: 572-587.

McFarland, J. W., Pettit, R. and Sung, S. K. 1982. The distribution of foreign exchange price changes: trading day effects and risk measurement. *Journal of Finance* **37**: 693-715.

Medeiros, M. and Veiga, A. 2004. Modeling multiple regimes in financial volatility with a flexible coefficient GARCH (1,1) model. *Testo para discussao 486*, Pontificia Universidade Catolica do Rio de Janeiro.

Melvin, M. and Taylor, M.P. 2009. The crisis in the foreign exchange market. *CEPR Discussion Papers No 7472*.

Perron, P. and Qu, Z. 2006. An analytical evaluation of the log-periodogram estimate in the presence of level shifts and its implications for stock return volatility. Mimeo. Boston University.

Phillips, P.C.B., McFarland, J. and McMahon, P.C. 1996. Robust tests of forward exchange market efficiency with empirical evidence from the 1920s. *Journal of Applied Econometrics* **11**: 1-22.

Simotsu, K. 2006. Simple (but effective) tests of long memory versus structural breaks. *Queen's Economics Department Working paper No. 1101*.

Smith, G.W. and Smith, R.T. 1990. Stochastic process switching and the return to gold, 1925. *Economic Journal* **100**: 164-175.

Taylor, M.P. and McMahon, P.C. 1988. Long –run purchasing power parity using cointegration techniques. *European Economic Review* **32:** 179-197.

Taylor, M.P. 1992. Dollar-sterling exchange rate in the 1920s: purchasing power parity and the Norman conquest of $4.86. *Applied Economics* **24**: 803-811.

Terasvirta, T. and Gonzalez, A. 2006. Modeling autoregressive process with a shifting mean. *Working paper no. 637*, Stockholm School of Economics.

Table 1: Descriptive Statistics for the daily USD-GBP Returns

	1920s	2010s
Mean	0.0097	-0.0005
Standard Deviation	0.2269	0.5214
Q(20)	25.2121	26.1149
$Q^2(20)$	152.4104	51.7609
Skewness	0.8152	0.0729
Kurtosis	9.4747	3.1085
ρ_1	0.0676	-0.0626

Key: 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. ρ_1 is the first order of autocorrelation.

Table 2: Estimation of GARCH and FIGARCH model for the Daily USD-GBP Returns

	1920s		2010s	
	GARCH model	FIGARCH model	GARCH model	FIGARCH model
μ	-0.0005 (0.0062)	-0.0004 (0.0058)	0.0003 (0.0167)	0.0033 (2033)
θ	0.1410 (0.0492)	0.1386 (0.0483)	-0.0675 (0.0391)	-0.0578 (0.0388)
d	-	**0.8644** **(0.1728)**	-	**0.2121** **(0.0613)**
ω	0.0039 (0.0014)	0.0043 (0.0014)	0.0025 (0.0020)	0.0520 (0.0246)
β	0.3816 (0.1001)	0.4932 (0.1307)	0.0309 (0.0137)	0.2079 (0.0696)
φ	0.6097 (0.0695)	-	0.9592 (0.0184)	-
ln(L)	220.186	229.808	-600.227	-594.264
m_3	1.076	1.088	-0.040	-0.027
m_4	8.771	8.923	2.964	3.014
Q(20)	23.627	24.806	19.188	18.856
$Q^2(20)$	7.604	7.110	10.374	14.123
$W_{d=0}$		19.244		12.026

Key: Robust standard errors are in parentheses below the corresponding parameter estimates. The symbol ln(L) refers to the value of the maximized log likelihood function, while m_3 and m_4 are the skewness and kurtosis respectively of the standardized residuals, while 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. The statistic $W_{d=0}$ is a robust Wald test for the GARCH(1,1) model against the FIGARCH(1,d,0) alternative.

Table 3: Estimation of Adaptive-GARCH and Adaptive -FIGARCH model for the Daily USD-GBP Returns

	1920s		2010s	
	Adaptive-GARCH model	Adaptive-FIGARCH model	Adaptive-GARCH model	Adaptive-FIGARCH model
μ	0.0055	-0.0001	0.0016	-0.0003
	(0.0052)	(0.0047)	(0.0167)	(0.0162)
θ	0.1525	0.1237	-0.0672	-0.0646
	(0.0448)	(0.0484)	(0.0386)	(0.0392)
d	-	**0.00797**	-	**0.1620**
		(0.0020)		**(0.0713)**
β	0.2504	0.5683	0.0257	0.0781
	(0.0653)	(0.0878)	(0.0145)	(0.0661)
φ	0.4290	-	0.9054	-
	(0.0941)		(0.0307)	
ω_0	0.0165	0.0165	0.0182	0.0603
	(0.0046)	(0.0046)	(0.0085)	(0.0226)
γ_1	-0.0037	0.0003	0.0061	0.0271
	(0.0024)	(0.0020)	(0.0031)	(0.0205)
δ_1	0.0034	0.0026	0.0019	0.0051
	(0.0020)	(0.0015)	(0.0021)	(0.0187)
γ_2	-0.0040	-0.0012	-0.0002	0.0370
	(0.0022)	(0.0014)	(0.0018)	(0.0187)
δ_2	0.0065	0.0010	0.0032	0.0681
	(0.0031)	(0.0016)	(0.0025)	(0.0585)
γ_3	-0.0055	-0.0018		
	(0.0029)	(0.0015)		
δ_3	0.0070	0.0015		
	(0.0031)	(0.0016)		
γ_4	-0.0022	0.0013		
	(0.0021)	(0.0016)		
δ_4	0.0009	0.0003		
	(0.0019)	(0.0011)		
γ_5	-0.0036	-0.0015		
	(0.0018)	(0.0013)		
δ_5	0.0043	-0.0018		
	(0.0020)	(0.0014)		
γ_6	-0.0070	-0.0021		
	(0.0028)	(0.0020)		
δ_6	0.0004	-0.0051		
	(0.0026)	(0.0019)		
γ_7	-0.0101	0.0014		
	(0.0034)	(0.0014)		
δ_7	0.0041	0.0015		
	(0.0025)	(0.0014)		
γ_8	-0.0006	0.0021		
	(0.0016)	(0.0014)		
δ_8	0.0036	-0.0015		
	(0.0020)	(0.0013)		

γ_9	-0.0007	-0.0014		
	(0.0016)	(0.0011)		
δ_9	0.0009	1.1188		
	(0.0017)	(0.1344)		
ln(L)	289.147	293.266	-595.443	-589.232
m_3	0.598	0.898	-0.023	-0.014
m_4	5.424	7.236	2.921	2.913
Q(20)	15.786	20.718	19.421	19.883
$Q^2(20)$	13.608	13.439	12.780	15.260
AIC	-528.294	-480.531	1208.886	1208.464
SIC	-406.491	-368.472	1251.093	1250.670
W_f		126.916		10.064

Key: Keys: The same as Table 2 except that the trigonometric terms k =9 for the 1920s returns and k=2 for the 2010s returns, which is selected based on the AIC (Akaike Information Criterion) and the SIC (Schwarz Information Criterion. The statistic W_f is a robust Wald test for the FIGARCH model against the Adaptive-FIGARCH model alternative.

Figure 1 (a): Daily USD-GBP Spot Exchange Rate from May 1, 1922 through May 30, 1925.

Figure 1 (b): Daily USD-GBP Spot Exchange Rate from May 3, 2010 through May 31, 2013.

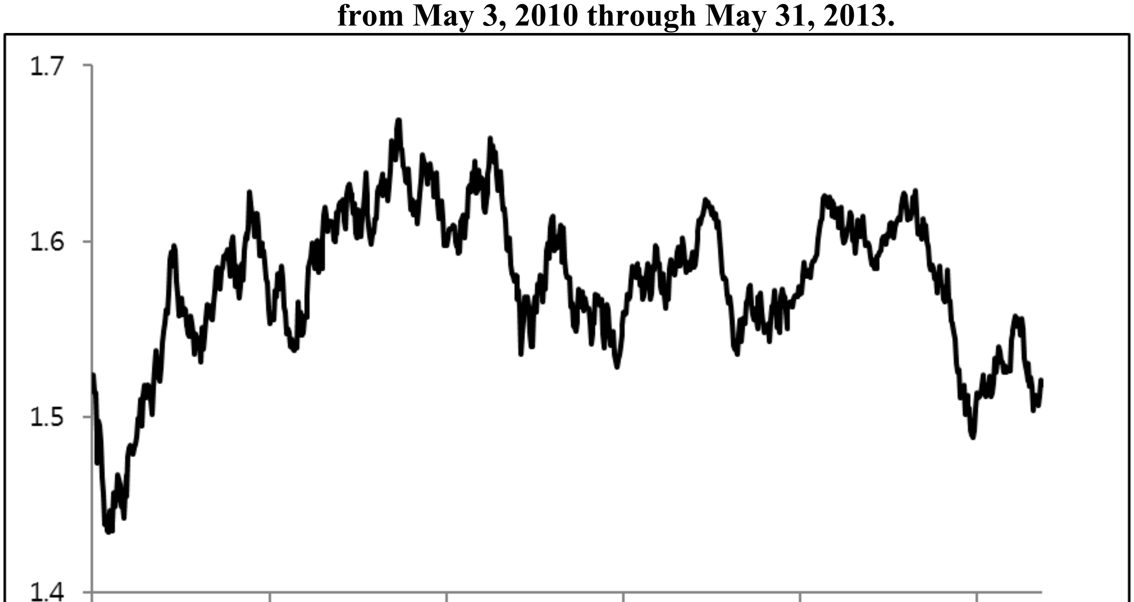

Figure 2 (a): Daily USD-GBP Spot Returns from May 1, 1922 through May 30, 1925.

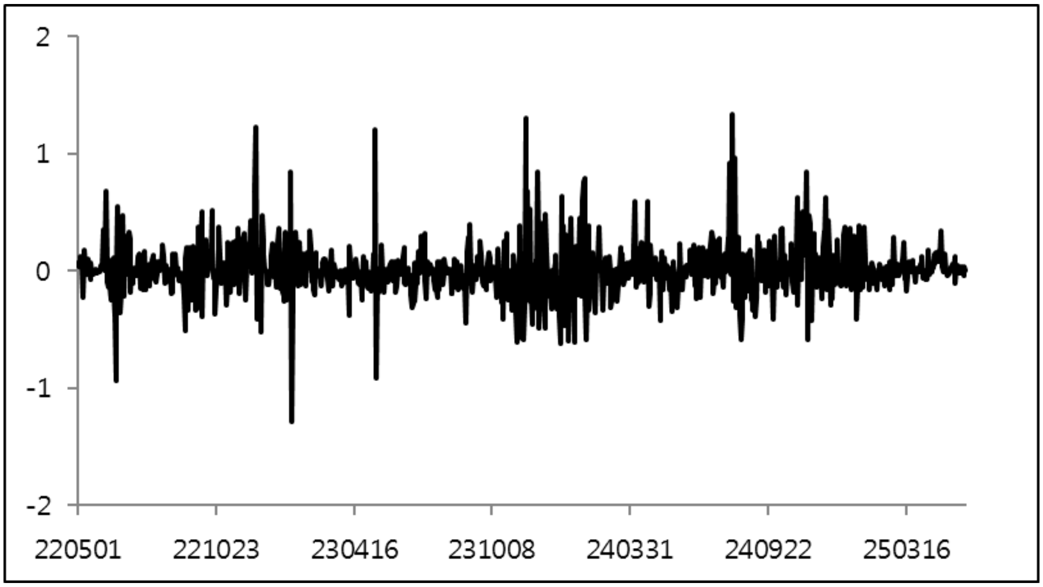

Figure 2 (b): Daily USD-GBP Spot Returns from May 3, 2010 through May 31, 2013.

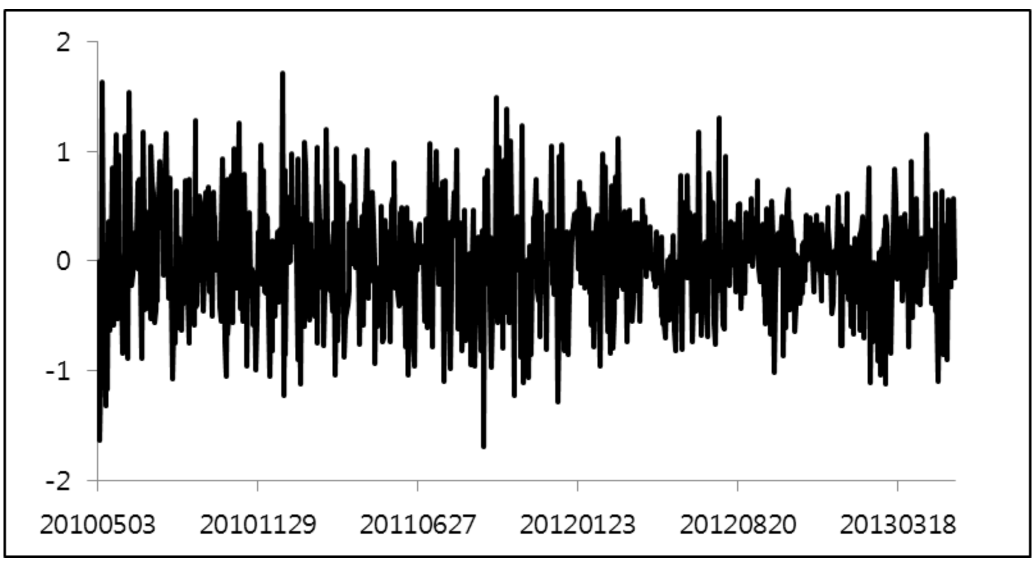

Figure 3 (a): Correlograms of Daily USD-GBP Spot returns in the 1920s

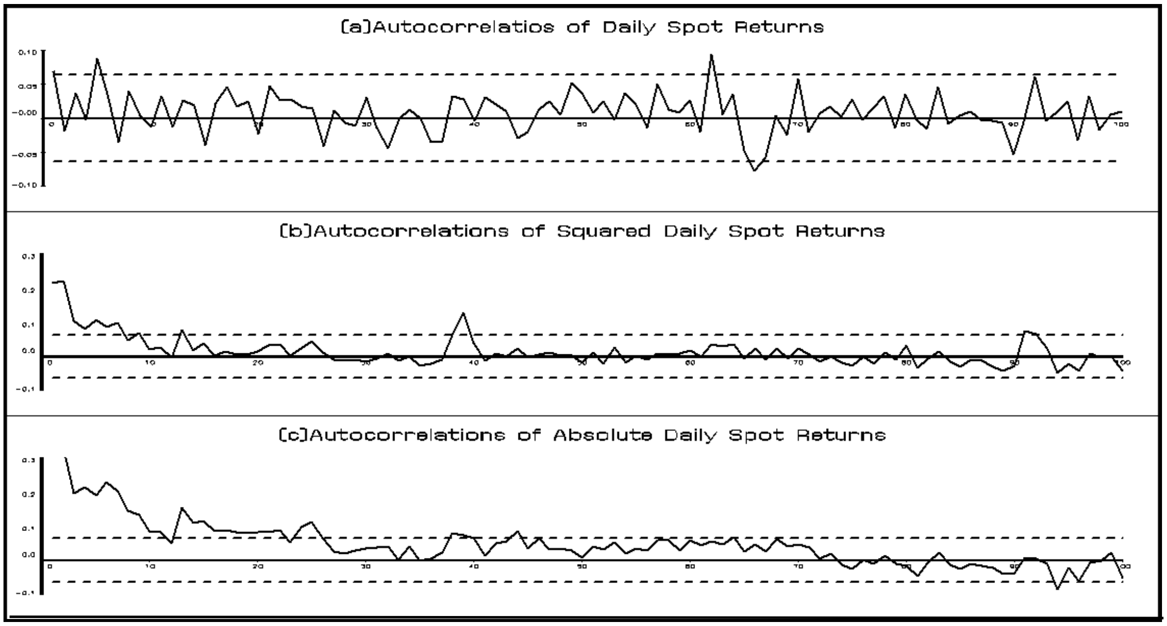

Figure 3 (b): Correlograms of Daily USD-GBP Spot returns in the 2010s