Poisson Jumps and Long Memory Volatility Process in High Frequency European Exchange Rates

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This paper analyzes the intriguing features of 30-minute European foreign exchange rates during the year 1996; jumps and long memory volatility process. The FIGARCH model with the Poisson distribution is applied in order to consider both the jumps in the conditional mean process and the long memory property in the conditional variance process of the high frequency foreign exchange returns series. The general results show that the Poisson distribution accounts for the jumps in the high frequency foreign exchange rates returns quite well and that the jumps seem to spuriously induce higher long memory property in the high frequency foreign exchange returns. Hence, the FIGARCH model with the Poisson distribution appears to be quite appropriate for the specification of the high frequency returns.

Keywords: High frequency foreign exchange rates, FIGARCH, Long memory property, Normal mixture distribution, Poisson jump process

JEL Classification: C13, C22, F31, G14

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I. Introduction

This paper is concerned with the intriguing features of the 30-minute high frequency exchange returns series obtained from the four different European foreign exchange rates of the Swiss Franc (CHF) - U.S. Dollar ($), the Deutsch Mark (DM) - U.S. Dollar ($), the French Franc (FF) - U.S. Dollar ($) and the U.S. Dollar ($) - British Pound (BP) during the year 1996. In particular, this paper explores two major issues involved in the representation of the high frequency European exchange returns. One issue is how to model the persistent long memory property underlying in the volatility process of the high frequency foreign exchange rate returns, and the other one is how to account for the jumps occurred in the high frequency returns and investigate their impacts on the high frequency foreign exchange returns.

First, this paper presents the U-shape intraday periodicity and the long memory property in the volatility process of high frequency exchange returns. After the intraday periodicity is eliminated by the Flexible Fourier Form (FFF) method of Gallant (1981, 1982), the long memory volatility process become a well documented feature of the high frequency exchange returns (Dacorgona *et al.* 1993; Andersen and Bollerslev 1997, 1998; Baillie *et al.* 2000). Even though the FIGARCH model with the normal distribution of Baillie *et al.* (1996) provides a better description to represent the long memory property in the volatility process of high frequency returns than the usual GARCH model (Baillie *et al.* 2000; Baillie *et al.* 2004; Beine *et al.* 2002a; Beine *et al.* 2002b; Beltratti and Morana 1999), the jumps in the high frequency exchange returns might lead to the “outliers” in the level and volatility process that can not be accounted for by the simple normal distribution model (Hotta and Tsay 1998).

Thus, this paper demonstrates the jumps in the high frequency exchange returns, which might be caused by several factors such as public news, private information or central bank interventions (Covrig and Melvin 2002; Andersen *et al.* 2003; Beine and Laurent 2003). These jumps may provide some strong implications for modeling the high frequency returns. Several empirical papers which analyze the impacts of jumps on the foreign exchange rates present that foreign exchange rates can be characterized by several jumps or large shifts followed by random movements (Ghosh 1997; Goodhart and Giugale 1993; Goodhart and Figliuoli 1992; Goodhart *et al.* 1993). Recently, Andersen *et al.* (2003) specified and estimated the model of high frequency exchange rate dynamics by allowing for the jumps caused by macroeconomic news (surprises) affecting both the conditional mean and the conditional variance at the same time. They showed that high frequency exchange rate movements are linked to macroeconomic news and high frequency volatility estimation can be improved by allowing for the jumps and that the markets react to the jumps in asymmetric fashion. And, Hotta and Tsay (1998) presented that the jumps might lead to the “outliers” in the level and volatility process that can not be accounted for by the simple normal distribution model. Hence, the jumps in the high frequency returns are of significant interest particularly since the long memory property in the volatility process of the high frequency returns cannot be extracted without any appropriate specification of the jumps.

This paper adopts the FIGARCH model with the assumption of the Poisson distribution in order to account for both the jumps and the long memory volatility process in the high frequency European exchange returns. The general estimation results from the FIGARCH model with the Poisson distribution show that the high frequency exchange returns contain significant jumps and that the long memory parameters are reduced significantly across the different high frequency returns after the jumps are appropriately accounted for. These results imply that the jumps seem to induce higher long memory parameters and that the FIGARCH model with the Poisson distribution can provide more appropriate estimates of the long memory parameters.

The plan for the rest of this paper is as follows: Section II presents the underlying features of the high frequency European foreign exchange rate returns. The high frequency returns are found to contain significant jumps in the mean process while the long memory persistence is presented in the volatility process after the strong intraday periodicity is eliminated by the FFF method. Section III analyzes the jumps and the long memory property in the high frequency returns by using the FIGARCH model and the Poisson distribution. In particular, the Poisson distribution is found to be appropriate in representing the jumps successfully and the FIGARCH model combined with the Poisson distribution is found to be effective in capturing the impacts of the jumps on the long memory volatility process of the high frequency returns data. The jumps seem to induce higher long memory parameters in the volatility process of the high frequency returns. Finally, Section IV provides a conclusion briefly.

II. Jumps and Long Memory Volatility Process

This section is concerned with a set of 30-minute CHF-\$, DM-\$, FF-\$, and \$-BP high frequency European foreign exchange rates provided by Olsen & Associates consisting of Reuter FXFX quotes taken every 30 minutes for the complete calendar year of 1996. During the year of 1996 the U.S. dollar had declined to a level more consistent with that of the "fundamental equilibrium exchange rate," and many of the European currencies were moving towards stability with the DM in preparation for the single market currency (Euro). The sample period is 00:30 GMT, January 1, 1996 through 00:00 GMT, January 1, 1997. Each quotation consists of a bid and an ask price and is recorded to the nearest second. Following the procedures of Müller *et al.* (1990), Dacorogna *et al.* (1993), and Baillie *et al.* (2000), the spot exchange rates for each 30-minute interval are determined as the linearly interpolated average between bid rates and ask rates. Hence the 30-minute return series is defined as the difference between the midpoints of the logarithmic bid and ask rates. The sample used in the subsequent analysis contains 262 trading days, each with 48 intervals of 30-minutes duration, which realizes a total of $T=12{,}576$ observations for 262 days.[1]

The high frequency 30-minute returns series of DM-\$ exchange rates are presented in Figure 1. The high frequency returns series of the DM-\$ exchange rates and the other exchange rates (not shown) are characterized by several large jumps or shifts followed by ostensibly random movement. A potential source of the jumps in the high frequency returns may be important events in foreign exchange markets such as public news, private information or central bank interventions (Covrig and Melvin 2002; Andersen *et al.* 2003; Beine and Laurent 2003). These events concerning expected future flows can result in price changes well above normal and might be better

[1] Since it has become very common to remove atypical data associated with slower trading patterns during weekends, the returns from Friday 21:00 GMT through Sunday 20:30 GMT are excluded.

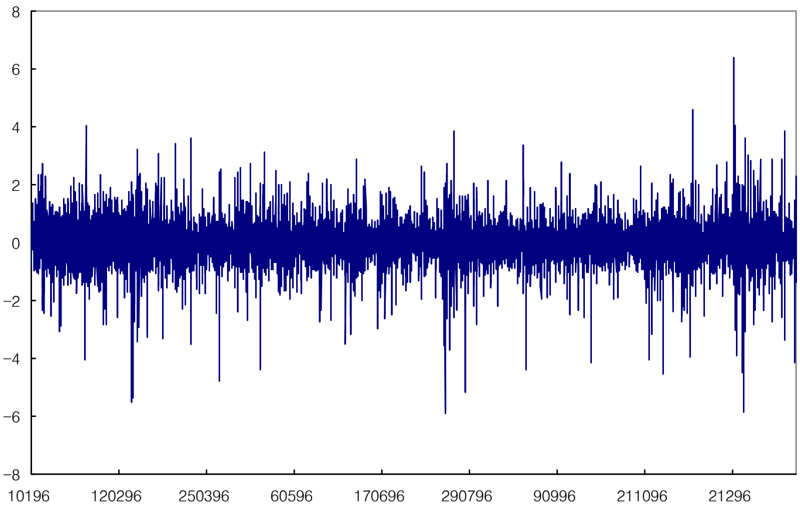

FIGURE 1
30-MINUTE DM-$ EXCHANGE RETURNS DURING 1996

captured by jumps rather than normal innovations. In particular, Andersen *et al.* (2003) presented evidence that the U.S. announcement surprises defined as the differences between expectations and realizations of macroeconomic fundamentals produce conditional mean jumps so that the dynamics of exchange rates is linked to economic fundamentals and the markets react to the jumps in asymmetric fashion. These jumps might lead to the level and volatility outliers which can not be taken into account for by the simple normal distribution as Hotta and Tsay (1998) presented.

Figure 2 plots the first 240 autocorrelations for the raw (unfiltered) returns, squared returns and absolute returns of the 30-minute DM-$ exchange rates. As usual there is a small, negative but very significant first order autocorrelation in returns, which can be attributed to a combination of a small time-varying risk premium, bid-ask bounce, and/or non-synchronous trading phenomena; see Goodhart and O'Hara (1997) for a description of this issue in high frequency currency markets. However, the autocorrelation functions of the squared and absolute returns display the pronounced U-shape pattern associated with substantial intraday periodicity and decay very slowly at the hyperbolic rate, which is a typical feature of a long

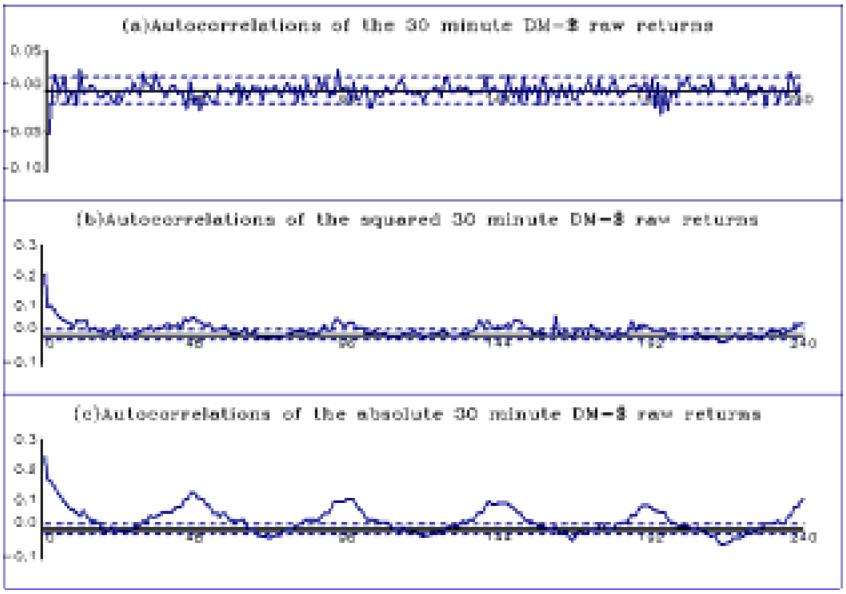

FIGURE 2
CORRELOGRAMS OF 30-MINUTE DM-$ EXCHANGE RAW (UNFILTERED) RETURNS

memory property.[2] The two features of the high frequency returns are more apparent in the autocorrelation functions of the absolute returns as presented by Granger and Ding (1995). These are generally in line with the findings of Wasserfallen (1989), Müller *et al.* (1990), Baillie and Bollerslev (1991), Dacorogna *et al.* (1993), Andersen and Bollerslev (1997, 1998) and Baillie *et al.* (2000).

In particular, some previous studies such as Andersen and Bollerslev (1997) and Baillie *et al.* (2000) have generally attributed such U-shape pattern to differences in the opening and closing times of the European, Asian and North American markets superimposed on each other. A further representation of this phenomenon is for example provided by Figure 3, which shows the averaged absolute 30 minute returns of DM-$ for each of the 48 intervals, representing the

[2] The corresponding correlograms of the other high frequency returns of CHF-$, FF-$, and $-BP exchange rates presents the similar patterns but they are not reported here to conserve space. They could be available by the request to the author.

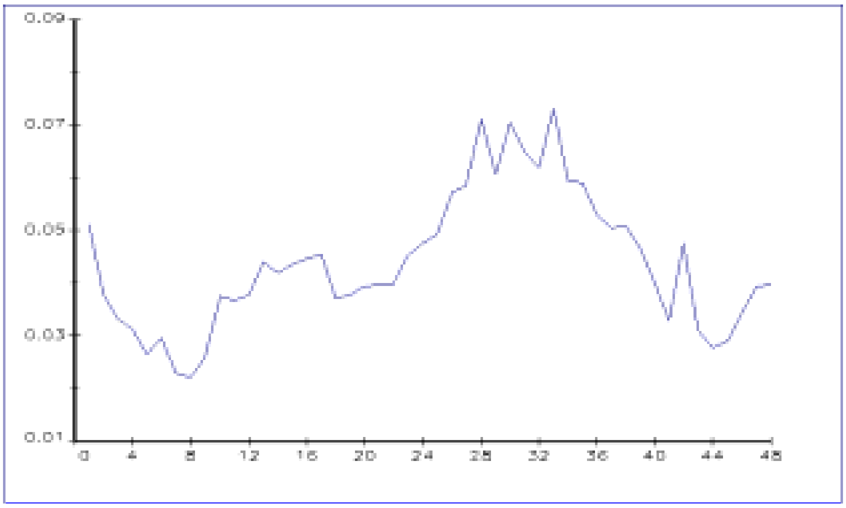

FIGURE 3
INTRADAY AVERAGE ABSOLUTE RETURNS OF 30-MINUTE DM-$ EXCHANGE RATES

intraday trading activity in foreign exchange markets over all the days in the year. While the strong drop in the absolute returns between intervals 8 and 10 corresponds to the lunch time in Asian markets like Tokyo and Hong Kong markets, the highest average absolute returns occur between periods 26 and 34 during the overlap of afternoon trading and in Europe markets and the opening of the U.S. markets. The corresponding graphs for the other currencies are not shown but they are found to display the similar trading activities in the foreign exchange markets around the world.

In order to remove the strong intraday periodicity properly, this study follows the Flexible Fourier Form (FFF) method of Gallant (1981, 1982) suggested by Andersen and Bollerslev (1998) and Baillie *et al.* (2000). See the Appendix of Andersen and Bollerslev (1997) for details of the FFF method. And, Baillie *et al.* (2000) presented that the FFF method appears to be appropriate for representing intraday periodicity without inducing any non-linearity and deficiencies with the model. Hence, the high frequency returns are filtered by the intraday periodicity, $P_{t,n}$ estimated from FFF method. For example, Figure 4 represents the estimated intraday periodicity ($P_{t,n}$) from the FFF method for the DM-$ exchange rates, which shows the quite

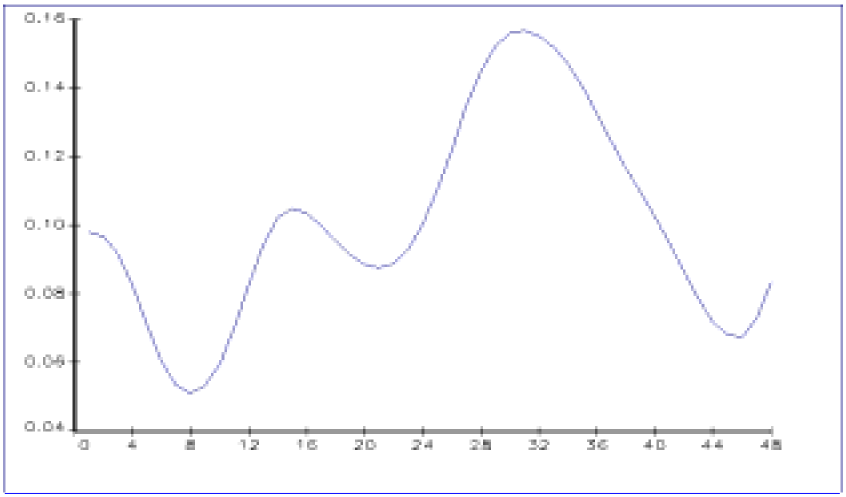

FIGURE 4
ESTIMATED INTRADAY PERIODICITY ($P_{t,\,n}$) OF DM-$ EXCHANGE RATES FROM FFF METHOD

similar intraday pattern to the overall intraday volatility pattern in the DM-$ foreign exchange markets in Figure 3.

The filtered returns are defined as

$$y_{t,\,n}=(R_{t,\,n}/P_{t,\,n}), \tag{1}$$

where $R_{t,\,n}=1000^{*}\Delta[\ln(S_{t,\,n})]$ and $S_{t,\,n}$ is the 30-minute foreign exchange rates. Figure 5 plots the first 240 autocorrelations for the filtered returns, squared returns and absolute returns of the high frequency returns of the DM-$ exchange rates. It shows that the first order autocorrelations in the returns are all small, negative, but very significant for the filtered high frequency DM-$ returns while higher order autocorrelations are not significant at conventional levels. The small autocorrelations can be attributed to a combination of a small time-varying risk premium, bid-ask bounce, and/or non-synchronous trading phenomena as discussed earlier. Furthermore, it is clear that the autocorrelations of the squared and absolute filtered returns dramatically reduce the U-shaped intraday periodicity and that the autocorrelation functions for the squared and absolute returns do

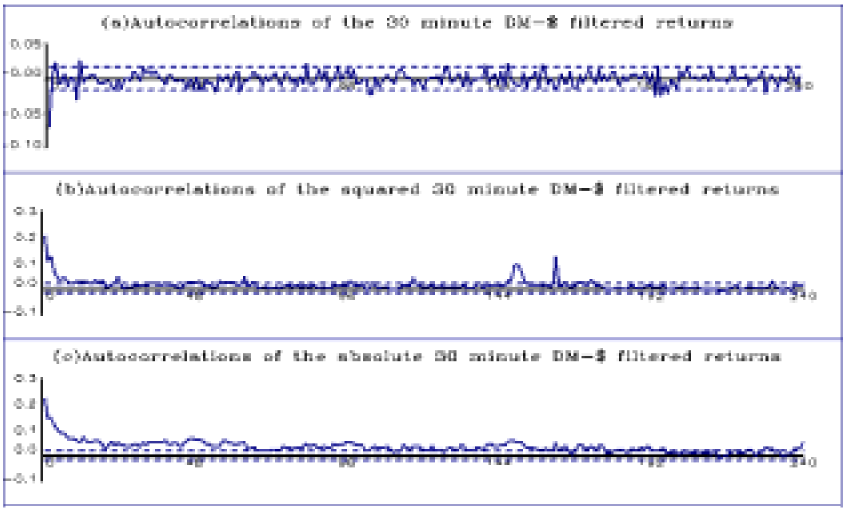

FIGURE 5
CORRELOGRAMS OF 30-MINUTE DM-$ EXCHANGE FILTERED RETURNS

not display the usual exponential decay associated with the stationary and invertible class of ARMA models, but rather appear to be generated by a long memory process with hyperbolic decay. Similar correlograms are also found for the filtered high frequency returns of the other exchange rates but they are not reported here to conserve space.

More formally, the long memory property can be introduced in terms of various properties of a time series process; see Baillie (1996). One of the most basic and intuitive ideas is through the properties of the autocorrelation function, which is defined as $\rho_k = Cov(x_t,\ x_{t-1})/Var(x_t)$ for integer lag k. A covariance stationary time series process is expected to have autocorrelations such that $\lim_{k\to\infty}\rho_k = 0$. Most of the well known class of stationary and invertible time series processes have autocorrelations that decay at the relatively fast exponential rate, so that $\rho_k \approx |m|^k$, where this property is true for example for the well known stationary and invertible ARMA $(p,\ q)$ process, $a(L)x_t = b(L)\varepsilon_t$, where $a(L)$ and $b(L)$ are p and q order polynomials in the lag operator L respectively, with all their roots lying outside the unit circle, while ε_t is a white noise process.

While many stochastic processes could potentially exhibit the long memory property, the most widely used such process is the ARFIMA

(p, d, q) model of Granger and Joyeux (1980), Granger (1980), and Hosking (1981). In the ARFIMA process a time series x_t is modeled as $a(L)(1-L)^d x_t = b(L)\varepsilon_t$ with $a(L)$ and $b(L)$ being polynomials in the lag operator L, with all their roots lying outside the unit circle, while ε_t is a white noise process. The ARFIMA process is stationary and invertible in the region of $-0.5<d<0.5$. At high lags the ARFIMA (p, d, q) process is known to have an autocorrelation function that satisfies $\rho_k \approx ck^{2d-1}$. Also, the impulse response weights defined in $x_t = \sum_{k=0}^{\infty} \psi_{t-k}\varepsilon_t$, have the property for large k that $\psi_k \approx c_2 k^{d-1}$, where c_2 is a constant and d is the long memory parameter. This type of persistence is very slow compared with exponential decay and such hyperbolic decay is sometimes known as the "Hurst phenomenon." The Hurst coefficient is defined as $H=d+0.5$. If $d=1$, so that $H=1.5$, the autocorrelation function does not decay and the series has a unit root. If $d=0$, so that $H=0.5$, then the autocorrelation function decays exponentially and the series is stationary. But for $0<d<1$, *i.e.* $0.5<H<1.5$, the series has a slower hyperbolic rate of decay in the autocorrelations. Hence for high lags, both the autocorrelations and impulse response weights decay at very slow hyperbolic rates, as opposed to the exponential rate associated with the stationary and invertible class of ARMA models. See Baillie (1996) for a fuller description of long memory models.

III. FIGARCH Model with the Poisson Distribution

Since the FIGARCH model with the normal distribution seems to represent the long memory volatility process of foreign exchange rates well as showed by Baillie *et al.* (2000), Beine *et al.* (2002a, 2002b), and Beine and Laurent (2003), it appears to be a good starting point to study the underlying features of the high frequency exchange returns. In particular, Baillie *et al.* (2000) investigated the long memory property in the volatility process of both high frequency 30-minute exchange rate returns with a relatively short time sample period (1-year) and low frequency daily returns with a long time sample period (20-years) and found that the FIGARCH model appears to successfully account for the long memory volatility process of the both frequency return series. Interestingly, the estimates of the long memory volatility parameter estimated from the FIGARCH models are found to be very consistent across the sample periods and the time aggregations.

The preliminary results based on the FIGARCH model with the normal distribution indicate that the estimated of the long memory parameters in the variance are 0.21, 0.20, 0.26, 0.22 for the high frequency returns of the CHF-$, DM-$, FF-$, and $-BP exchange rates respectively and they are all strongly statistically significant implying that the FIGARCH model is superior to the GARCH model for modeling the conditional variances of high frequency exchange returns.[3] Evidently, the long memory is a characteristic feature of the high frequency returns, and the FIGARCH represents a significant improvement over the GARCH, which is in line with the results of Baillie *et al.* (2000), Beine *et al.* (2002a, 2002b), and Beine and Laurent (2003).

However, the jumps in high frequency exchange returns presented in Figure 1 might lead to the "outliers" in the level and volatility process that can not be accounted for by the simple normal distribution model (Hotta and Tsay 1998). Hence, this study employs the jump diffusion process proposed by Press (1967) in order to account for the jumps and the long memory volatility process in the 30-minute high frequency European exchange returns. Initially, Press (1967) proposed a jump diffusion model for stock prices under the assumption that the logarithm of the stock price follows a Brownian motion process on which i.i.d. normal distributed jumps are included. Jorion (1988) used a Press-type model to find some statistical evidence of jumps in the U.S.$-DM exchange rate for the post 1971 free floating period. This jump diffusion model has subsequently been widely employed to model features of Exchange Rate Mechanism (ERM) of European Monetary System (EMS) such as the jumps resulting from realignments of the ERM bands (Vlaar and Palm 1993; Nieuwland *et al.* 1994; Neely 1999; Baillie and Han 2001). Baillie and Han (2001) considered a model in discrete time providing a relatively simple formulation to investigate a target zone model while Chung and Tauchen (2001), Ball and Roma (1993) and others favored continuous time models and use jump diffusion processes for the analysis of foreign exchange rates in the EMS under a target zone model.

[3] The estimation results from the MA(1)-FIGARCH(1, d, 1) model with the normal distribution are not reported here to conserve space but are available upon request.

In economic literature, stochastic jumps are mostly modeled by means of the Poisson distribution (Akgiray and Booth 1988; Hsieh 1989; Nieuwland *et al.* 1991) or the Bernoulli distribution (Vlaar and Palm 1997; Neely 1999; Beine and Laurent 2003). The main difference is that the Poisson process models large changes as a sequence of several jumps occurring within a given period while the Bernoulli process assumes there exits only one jump within a given period. But, modeling the probability of the jumps in high frequency exchange returns as a Poisson trial seems to be more realistic for modeling the high frequency returns by allowing more than one jump even in a short time interval since several jumps in foreign exchange rates can occur even during the short period of 30 minutes by several factors like new public or private information in foreign exchange markets. Thus, the Poisson distribution is used in this study.[4]

The model that is consistent with these stylized facts is the MA(n)-FIGARCH(p, d, q) process with the Poisson distribution,

$$y_{t,\,n}=\mu+(\lambda\times\nu)+b(L)\varepsilon_{t,\,n} \tag{2}$$

$$\varepsilon_{t,\,n}\sim(1-\lambda)N(-\lambda\nu,\ \sigma^2_{t,n})+\lambda N(\nu-\lambda\nu,\ \sigma^2_{t,n}+\delta^2) \tag{3}$$

$$\sigma^2_{t,n}=\omega+\beta(L)\sigma^2_{t,n-1}+[1-\beta(L)-(1-\phi(L))(1-L)^d]\varepsilon^2_{t,n} \tag{4}$$

where μ and ω are scalar parameters, and $b(L)$, $\beta(L)$, and $\phi(L)$ are polynomials in the lag operator to be defined later. For the Poisson distribution, the jump probability (λ) is forced in the (0, 1) interval and the jump size is assumed to be NID(ν, δ^2). Thus, ($\lambda\times\nu$) denotes the contribution of jumps to the exchange rate returns. In particular, the polynomial in the lag operator associated with the moving average process is, $b(L)=1+b_1L+b_2L^2+\cdots+b_nL^n$, and d continues to represent the long memory parameter. And, the FIGARCH model in Equation (4) is motivated by noting that the standard GARCH (p, q) model of Bollerslev (1986) can be expressed as $\sigma^2_t=\omega+\alpha(L)\varepsilon^2_t+\beta(L)\sigma^2_t$, where the polynomials are $\alpha(L)\equiv\alpha_1L+\alpha_2L^2+\cdots+\alpha_qL^q$ and $\beta(L)\equiv\beta_1L+\beta_2L^2+\cdots+\beta_pL^p$. The GARCH ($p$, q) process can also be

[4] The estimation results from the Bernoulli process are generally found to be similar to those from the Poisson process (Vlarr and Palm 1993; Han 2007). The results of the Bernoulli model are available upon request.

expressed as the ARMA [max (p, q), p] process in squared innovations $[1-\alpha(L)-\beta(L)]\varepsilon_t^2=\omega+[1-\beta(L)]v_t$ where $v_t\equiv\varepsilon_t^2-\sigma_t^2$, 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

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

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 (4), 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 to decay at a slow hyperbolic rate.

The above model (2), (3), and (5) is estimated for the high frequency returns on the four European exchange rates of interest by maximizing the Gaussian log likelihood function,

$$\ln(\xi)=-T\lambda-(T/2)\ln(2\pi)+\textstyle\sum_{t=1,..262,\ n=1,...,48}\ln\{\sum_{j=0,\infty}\lambda^j/ \\ [j!((\sigma_{t,n}^2+\delta^2 j)^{1/2}]^*\exp[-(\varepsilon_{t,n}-(j-\lambda)v)^2/2(\sigma_{t,n}^2+\delta^2 j)]\} \tag{6}$$

The form of the likelihood function for the Poisson jump processes is basically the same as that developed by Vlaar and Palm (1993) and Baillie and Han (2001). To make the infinite sum estimable, the sum is truncated after 11 terms following the Ball and Torous (1983) method. 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 (2), (3), and (5). Then the limiting distribution of $\hat{\Theta}_T$ is

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

where $A(\bullet)$ and $B(\bullet)$ 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.

The exact parametric specification of the model that best represents the degree of autocorrelation in the conditional mean and conditional variance of the high frequency exchange returns is MA(1)-FIGARCH (1, d, 1) model for the four currencies. The orders of the MA 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 high frequency data. Since the statistical and economic motivations for the jumps and the long memory property are quite different, this work chooses the model specification that accounts for the two features at the same time. Thus, this work investigates the jumps and the long memory property in the high frequency returns of the CHF-$, the DM-$, the FF-$, and the $-BP exchange rates by employing the MA(1)-FIGARCH(1, d, 1) model with the Poisson distribution. Table 1 presents results of applying the above model to the high frequency returns for the four European foreign exchange rates discussed earlier.

The estimation results reported in Table 1 appear to describe the high frequency exchange returns data rather well. For each currency there is strong evidence of small moving average effect (b) in the mean returns. As stated earlier, this may be attributed to a combination of a small time-varying risk premium, bid-ask bounce, and/or non-synchronous trading phenomena. Similar features for high frequency exchange rate returns are noted by Andersen and Bollerslev (1997), Baillie *et al.* (2004), Goodhart and Figliuoli (1992), Goodhart and O'Hara (1997), and Zhou (1996). The foot of the Table 1 presents the Box-Pierce portmanteau test statistic for auto-correlation in the standardized residuals. The standard portmanteau test statistic, $Q(m)=T(T+2)\ \sum_{j=1}^{m} r_j^2/(T-j)$, where r_j is the j'th order sample autocorrelation from the residuals, is known to have an asymptotic χ^2_{m-k} distribution, where k is the number of parameters estimated in the conditional mean. Similar degrees of freedom adjustments are used for the portmanteau test statistic based on the squared standardized residuals when testing for omitted conditional heteroscedasticity. This adjustment is in the spirit of the suggestions by Diebold (1988) and others. The sample skewness and kurtosis of the standardized residuals ($m3$ and $m4$), are also provided at the bottom of Table 1. The Box-Pierce portmanteau statistics show that the models specified for each currency do a good job of capturing the

TABLE 1

ESTIMATED MA(1)-FIGARCH(1, δ, 1) MODEL THE POISSON JUMP PROCESS WITH FOR THE 30-MINUTE EXCHANGE RETURNS

	CHF-$	DM-$	FF-$	$-BP
μ	0.0044	0.0092	0.0137	0.0052
	(0.0061)	(0.0043)	(0.0041)	(0.0040)
λ	0.1714	0.1109	0.1105	0.1341
	(0.0317)	(0.0182)	(0.0144)	(0.0218)
ν	0.0011	-0.0670	-0.0957	-0.0183
	(0.0382)	(0.0450)	(0.0499)	(0.0364)
δ^2	1.7646	1.3645	2.0071	1.1437
	(0.3040)	(0.2195)	(0.3030)	(0.1869)
b	-0.1338	-0.1019	-0.1645	-0.2002
	(0.0094)	(0.0096)	(0.0102)	(0.0103)
d	0.1120	0.1125	0.1045	0.1272
	(0.0165)	(0.0272)	(0.0109)	(0.0125)
ω	0.0011	0.0025	0.0014	0.0015
	(0.0018)	(0.0039)	(0.0007)	(0.0005)
β	0.9007	0.8901	0.9244	0.9353
	(0.0270)	(0.1388)	(0.0160)	(0.0114)
φ	0.8890	0.8836	0.9121	0.9164
	(0.0253)	(0.1300)	(0.0162)	(0.0149)
ln(L)	-14098.525	-10612.359	-11151.069	-10136.545
$m3$	-0.105	-0.278	-0.096	-0.360
$m4$	9.935	9.901	13.173	10.666
$Q(50)$	75.582	63.297	64.480	60.151
$Q2(50)$	52.910	33.921	88.511	171.614

Note: QMLE asymptotic standard errors are in parentheses below corresponding parameter estimates. The quantity ln(L) is the value of the maximized log likelihood. The sample skewness ($m3$) and kurtosis ($m4$) refer to the standardized residuals. The $Q(50)$, $Q2(50)$, and $Q3(50)$ statistics are the Ljung-Box test statistics for 50 degrees of freedom to test for serial correlation in the standardized residuals, squared standardized residuals and absolute standardized residuals.

autocorrelations in the mean and volatility of the high frequency exchange return series. In each case there is no evidence of additional autocorrelation in the 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 standardized residuals from the currencies, except $-BP, exhibit the usual features of non-normality of the high frequency exchange returns.

And, the estimated jump probability (λ) for the high frequency returns are all significant at the conventional level of significance implying that the jumps are very apparent in the conditional mean process and that the Poisson process appears to be quite appropriate to account for the jumps. The jump probabilities (λ) are 0.17, 0.11, 0.11, and 0.13 for the CHF-\$, the DM-\$, the FF-\$, and the \$-BP returns series respectively. The interpretation of the λ parameters indicates that the DM-\$ and the FF-\$ foreign exchange markets seem to be more stable during 1996 than the CHF-\$ and the \$-GBP markets. Within the one year series of 12,576 30-minute observations, the corresponding implied numbers of the jumps are approximately 2137, 1383, 1383, and 1634 for the CHF-\$, the DM-\$, the FF-\$, and the \$-BP returns series respectively. In particular, given the fact that there have been approximately total 720 public news (420 U.S. and 300 German) related to macroeconomic fundamentals released from the U.S. and Germany during 1996, about 50% of the jumps in the DM-\$ exchange rates seem to be caused by the public news.[5] One interesting issue concerns the interpretation of the jumps whether or not they correspond to public economic news, private information, or economic policies. However, without more detailed information, it is difficult to distinguish these effects.

The estimated parameters (υ) which represent the impacts of the jumps on the mean process are found to be very weak and insignificant for all high frequency returns. This may be because of the very quick adjustments of exchange rates to the jumps as reported by Andersen *et al.* (2003). However, the effects of the jumps on the volatility process (δ^2) are estimated to be very significant and much greater than those on the conditional mean process suggesting that the jumps affect the volatility process more significantly.

The focus of this paper is primarily directed at the long memory parameter *d*. The results in Table 1 show that the estimated long memory parameters (*d*) of the high frequency returns are 0.11, 0.11, 0.10, and 0.13 for the CHF-\$, the DM-\$, the FF-\$, and the \$-BP high frequency returns respectively and they are all very significant. Interestingly, the values of the estimated long memory parameters

[5] The data for the public macroeconomic news of the U.S. and Germany is provided by MMS (Money Market Service) International during 1996.

are found to be reduced by more than 50% compared with the values estimated from the FIGARCH model with the normal distribution and they appear to be more consistent across the European currencies than those from the basic FIGARCH models without considering the jumps. This suggests statistical evidence that the jumps may induce the higher long memory estimates in the volatility process of the high frequency returns implying that the increased volatility resulting from jumps may be captured by the higher value of *d* in the FIGARCH model with the normal distribution. These estimation results are quite consistent with the findings of Beine and Laurent (2003) which used ARFIMA-FIGARCH model with Bernoulli jump process for the analysis of daily exchange rates. Similarly, the decrease of the persistence of shocks when accounting for jumps in exchange rates is addressed in several papers such as Diebold and Inoue (1999), Beine and Laurent (2001), and Granger and Hyung (2004) focusing on accounting for long memory or on modelling structural changes as substitutes for each other.

Thus, the long memory property seems to be closely related to the conditional variance adjustments to the jumps, which is more gradual and persistent than the conditional mean adjustments. And the jumps seem to be the possible underlying driving forces behind the long memory property in the volatility process of the high frequency returns as presented by Andersen *et al.* (2003). These results confirm the facts that the higher long memory parameters of the volatility process may be closely linked with the asymmetric movements of the jumps caused by several factors such as public news, private information, or central bank interventions in foreign exchange markets.

IV. Conclusions

This paper considers the high frequency European exchange returns series of the CHF-$, the DM-$, the FF-$, and the $-BP foreign exchange rates for the year of 1996 and investigates the intriguing features of the high frequency returns data. The 30-minute high frequency returns are all found to contain significant jumps in the conditional mean process and also to exhibit long memory persistence in the conditional variance process after the strong intraday periodicity is filtered by the Flexible Fourier Form (FFF) method. Even though the preliminary test suggests that the FIGARCH model with the normal distribution appears to be a good starting point to specify the high frequency exchange rate returns well, the usual normal distribution is found to be inappropriate in accounting for the occurrence of the jumps in the high frequency exchange returns. The jumps may lead to the level and the volatility outliers in the high frequency returns and cannot be taken accounted by the normal distribution. Thus, this paper adopts the Poisson distribution to account for the jumps. In particular, this paper generalizes the FIGARCH model by combining with the Poisson jump process in order to account for both the jumps and the long memory volatility process in the high frequency returns since the long memory property in the volatility process of the high frequency returns cannot be extracted without any appropriate specification of the jumps. The FIGARCH model with the Poisson distribution appears to be quite proper to represent the jumps and the long memory property in the high frequency returns series. The estimated long memory parameters from the FIGARCH model with the Poisson distribution are found to be reduced compared with those from the basic FIGARCH model with the normal distribution. This constitutes strong evidence that the jumps can cause higher values of the long memory parameters in the volatility process of the high frequency returns series.

Hence, the FIGARCH model with the Poisson distribution appears quite appropriate in describing the jumps in the high frequency returns. And, this model seems to be helpful in deepening our understanding of high frequency foreign exchange rate dynamics by distinguishing the underlying forces behind the long memory property in the volatility process of high frequency exchange rates.

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