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Jumps and Long Memory Volatility Property in Daily Crude Oil Prices: Case of the Dubai Oil*

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Abstract

This paper considers the dynamic evolution of the crude oil prices by using the daily Dubai oil data. In particular, this paper investigates the jumps and the long memory volatility property, which have led the unstable path and the volatility persistence in the oil prices. First, this paper documents statistical evidence for long memory property in the volatility process of the daily oil price returns by using the FIGARCH model. This paper then finds that there exit significant jumps in the conditional mean process of the oil price returns. Hence, this paper relies on a normal mixture distribution that allows for Bernoulli jumps in the process of the daily oil price returns. The results of this paper find that the daily oil price returns contain the long memory property in the volatility process and that a considerable part of the long memory volatility property is attributed to the jumps inducing higher long memory parameters.

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Ⅰ. Introduction

Crude oil is one of the most important commodities in the world economies among many traded primary commodities and is an important input factor influencing all economic sectors (Bacon, 1991). Economists have analyzed the oil prices empirically to explain the characteristics and the causes of the price evolution, and noted that the movements of the oil prices are over-volatile and exhibit jumps (price spikes) over time (Agnolucci, 2008; Askari and Krichene, 2008; Wirl, 2008; Vo, 2009; Wei et al., 2010). Thus, the volatility behavior and the jumps in the oil prices have become the central topic for risk management and investment strategy in oil markets, and many market participants and academics have a strong interest in identifying and measuring both the volatility and the jumps of the oil prices.

Many econometric models have attempted to explain the long memory volatility and the jumps in the oil prices but they have considered them separately.[1)] For instances, Martens and Zein (2004) and Brunetti and Gilbert (2000) use the FIGARCH (Fractionally Integrated Generalized Autoregressive Conditional Heteroskedasticity)-type models to estimate the long memory volatility property

1) Some studies including Granger and Hyung (2004) and Choi and Zivot (2007) present that spurious long memory volatility can be due to the presence of occasional structural breaks detected in time series data.

in crude oil futures prices while Askari and Krichene (2008), Lee et al.(2010) and Gronwald (2011) apply GRARCH(Generalized Autoregressive Conditional Heteroskedasticity) models with jump diffusion process to capture jumps or extreme price movements in oil prices.

Even though the previous studies have provided valuable information on the oil price evolution, they have not explained the dynamics of the oil prices clearly since it has been difficult to find any specification model to consider the long memory volatility and the jumps together and still there have been few applications of the model to the oil prices. The main contribution of this paper to the oil price literature is that this paper focuses on identifying the long memory volatility and the jumps simultaneously in the dynamics of the oil prices. In particular, this paper investigates the stochastic properties of the daily oil prices and applies a different method in modeling both the long memory volatility and the jumps in order to provide important implications for empirical works. First, this paper focuses on the long memory volatility property which is apparent in various measures of the volatility of the daily oil prices by using the FIGARCH model (Martens and Zein, 2004; Brunetti and Gilbert, 2000).[2] Then, this paper considers the jumps in the returns of the oil prices, which affect the volatility process significantly. In fact, the long memory property in the conditional variance process cannot be represented if the conditional mean process is not appropriately specified. Thus, this paper uses the FIGARCH - Bernoulli jump process model which is a kind of a normal mixture distribution model in order to investigate the presence of the jumps and the relative contribution of the jumps to the volatility process of the daily oil prices.

Since the specification of the conditional mean process without considering the jumps seems to cause distorted higher estimates of the long memory parameter in

2) The long memory persistence pattern can be found in similar oil and energy futures prices (Chung, 2008; Elder and Serletis, 2008; Alvarez-Ramirez et al., 2008).

the volatility process, this is very clear that the jumps associated with additional volatility are fully accounted for in the mixture distribution. The main results of this paper can provide the better understanding in the dynamics of the daily oil prices and empirical applications such as risk management and portfolio management in the oil markets.

The rest parts of this paper are as follows. Section II statistically describes the daily crude Dubai oil price data which is one of the most important input factors in the Korean economy and presents the long memory volatility property in the daily oil price returns by estimating the FIGARCH model. Section III of the paper then analyzes the jumps in the conditional mean process of the daily oil price returns using a normal mixture distribution model. The FIGARCH model with Bernoulli jump process is used to represent the conditional mean jumps and the long memory property volatility in the daily oil price returns. Finally, section IV provides a brief conclusion.

Ⅱ. Long Memory Volatility Property in the Oil Prices

The crude Dubai oil is one of the most important input factors influencing all economic sectors in the Korean economy, and about 90% of the total oil imports in Korea are the Dubai oil produced by the OPEC countries. Thus, the empirical analysis of this paper focuses on the daily crude Dubai oil price data obtained from the Thomson Reuters. The oil prices are for real time transaction records, and they are the last prices quoted in terms of the USD per barrel at the closing time of the trading day in the SIMEX(Singapore Mercantile Exchange). The sampling period of the daily oil price data is from January 3, 2006 through

November 29, 2010 with total 1261 observations after excluding the weekends and the worldwide holidays. The corresponding returns (percentage changes of the prices) for the analysis are computed from the log differences in the daily Dubai oil prices,3)

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

where y_t denotes the continuously compounded returns for the daily Dubai oil prices at time t, and P_t denotes the daily Dubai price at time t.

Figure 1(a) presents the movements of the daily crude Dubai oil prices during the sample periods. The movements of the oil prices could be closely related to several events in the economic and geo-political aspects.4) For example, (1) the oil prices have risen due to global economic growth in 2006-2007; (2) the oil prices have experienced the price decrease due to the US recession in 2007-2008; (3) the oil prices have achieved their peak up to $140 in the Summer of 2008 and then bottomed down at $40 again from the Fall to January 2009 due to the speculations in the oil markets and Lehman bankruptcy; (4) the oil prices have rebounded on the concern about the political unrests in the North Africa region. Figure 1(b) also displays the returns series of the daily Dubai oil prices showing that the returns are centered around zero with significant volatility clustering and characterized by some large jumps followed by apparently random movements due to several economic and political events. As presented by Gronwald (2011), the jumps appear to be related to the high volatility of the returns.

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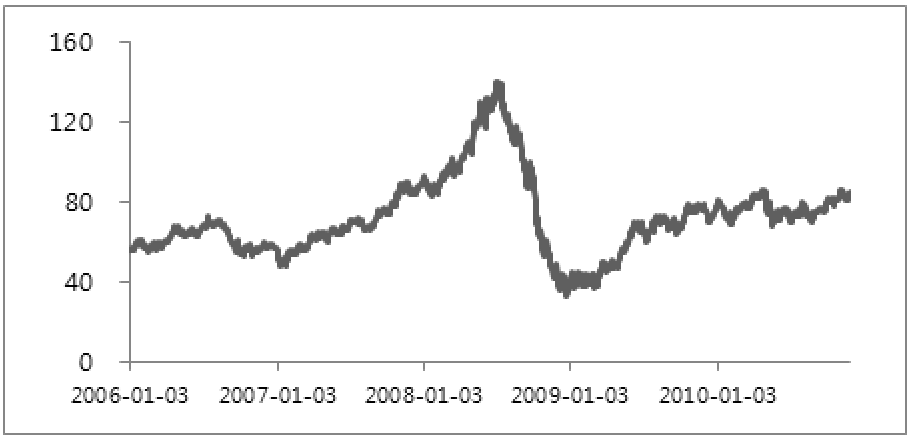
3) This paper also examines two other key crude oils, the West Texas Intermediate (WTI) and the North Sea Brent (Brent) with the same sample periods for the comparison and finds quite similar results to the Dubai oil prices. Thus, the results are not included in this paper but they are available for the request.

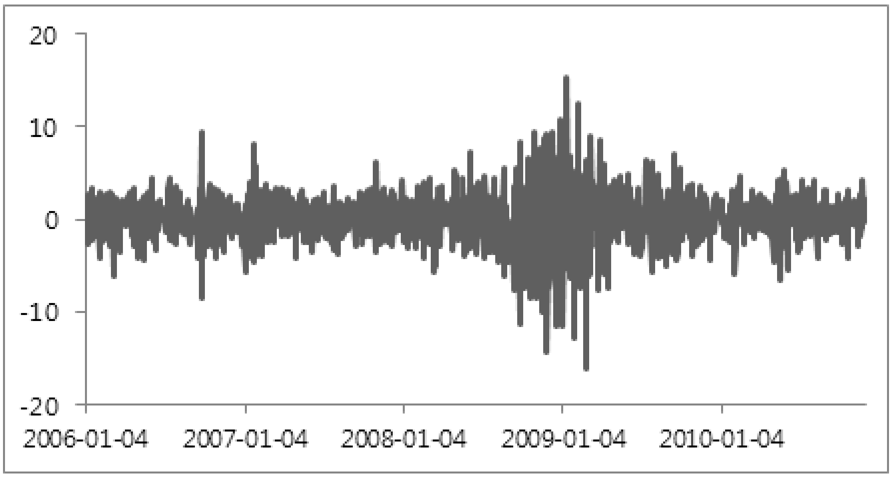
4) See Rapaport (2012) for the details of the major events that affected the crude oil markets.

Figure 1: Daily Crude Dubai Oil Prices and Returns

(a) Daily Oil Prices



(b) Daily Oil Price Returns



In particular, the oil prices movements with the extremely high volatility and the sudden raises followed by the slower declines could be because the oil which is so extensively consumed has a huge impact on the world economy. The rising cost of oil may cause stagflation by pushing up prices of the other commodities and fueling inflation on one hand and by reducing demand and increasing unemployment on the other. Thus, the oil price trends, hikes and volatility have posed some treats to the world economy and revived the debate on the oil price dynamics in order to model the significant movements of the oil prices and manage the risks inherent to the volatile changes in the oil prices.

Table 1: Descriptive statistics for the daily Dubai oil price returns

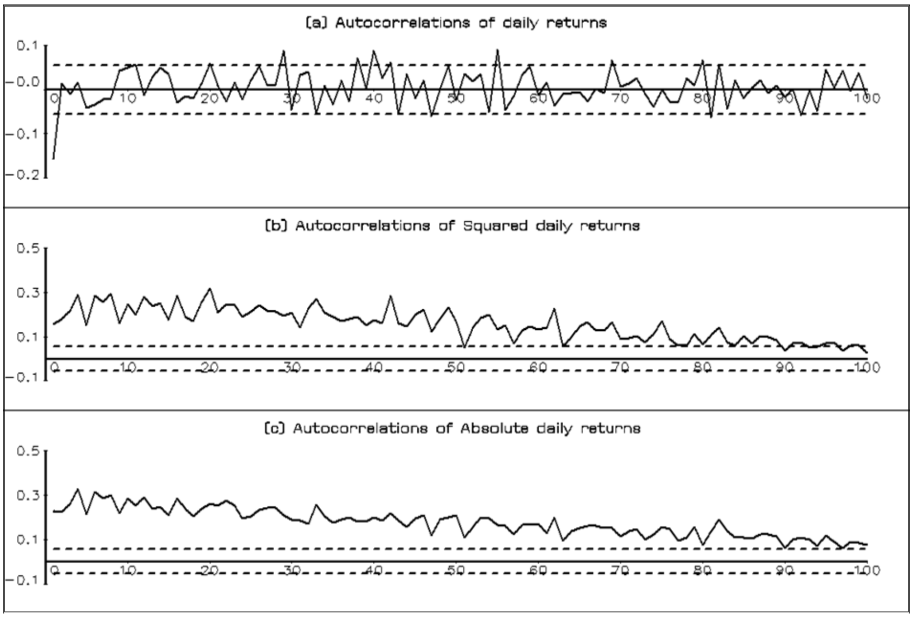
mean	0.033
variance	7.771
Q(20)	58.695
$Q^2(20)$	415.349
ρ_1	-0.157
skewness	-0.227
kurtosis	6.887

keys: The Q(20) and $Q^2(20)$ statistics are the Ljung-Box test statistics for 20 degrees of freedom to test for serial correlation in the returns and squared returns. ρ_1 is the value of the first order autocorrelation in the returns.

Also, the details of the descriptive statistics for the returns of the daily Dubai oil prices are provided in Table 1. The sample means of the returns are all quite small with the value of 0.03, which are very close to zero while the corresponding variances are much higher with the value of 7.77. And, the value of the first order autocorrelation in the returns of the Dubai oil prices is found to be negatively small but statistically significant, which may be due to small risk premium and/or non-synchronous trading in the oil markets. And, the distribution of the returns appears not to be normally distributed as are indicated by the Ljung-Box tests, skewness and kurtosis. The Ljung-Box test statistics (Q^2) with a lag of 20 for the squared returns of the oil prices reject the null hypothesis of no serial correlation in the volatility process at the standard significance level, implying that the squared returns all exhibit significant signs of serial correlation. And, the value of the kurtosis is found to be large (the high excess kurtosis) due to the numerous jumps in the returns.

For the further analysis on time series property in the returns of the oil prices, Figures 2 plots the correlograms which represent the first 100 autocorrelations in order to check the serial correlations of the raw returns, squared returns and absolute returns. Just as presented in the descriptive statistics in Table 1, the first order autocorrelation in the raw returns of the Dubai oil prices is negatively small but statistically significant while higher order autocorrelations are not significant at

Figure 2: Correlogram of the Daily Returns for the Crude Dubai Oil Prices



Keys: The dotted line represents the band in which there is no serial correlation at the 95% confidence level conventional levels. However, the autocorrelation functions represented in both the squared and absolute returns of the daily oil prices show a typical feature of a long memory volatility property, which is very slow decays at the hyperbolic rate. This finding is in line with the findings of Martens and Zein (2004) and Brunetti and Gilbert (2000) who studied the volatility process of the crude oil futures data.

Thus, the appropriate model to represent these stylized facts is the MA(Moving Average)(1)-FIGARCH(1, d, 0) model. In particular, several tests for model mis-specification do not reveal any obvious deficiencies with the model. And the robust Wald tests of the GARCH (1, 1) null hypothesis versus a FIGARCH (1, d, 0) alternative hypothesis provide an overwhelming rejection of the GARCH(1, 1) formulation, which is similar to Jin and Frechette (2004). The MA(1)-FIGARCH (1, d, 0) model can be specified as the followings;

$$y_t = 100^*[in(P_t) - in(P_{t-1})] = \mu + \theta\varepsilon_{t-1} + \varepsilon_t \tag{2}$$

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

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

where z_t $i.i.d.(0,1)$, μ and ω are scalar parameters, and the parameter (*d*) represents the long memory parameter.

In particular, the long memory parameter (*d*) specifies the long memory property in volatility because it shows the autocorrelations which are decaying at a slow hyperbolic rate. For 0<d<1, the FIGARCH model implies a long memory behavior and is strictly stationary and ergodic. (Baillie et al., 1996). The above model is estimated for the returns of the daily oil prices by maximizing the Gaussian log likelihood function,

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

where Θ is a vector which contains some unknown parameters to be estimated. However, most asset returns are not specifies clearly if z_t in equation (3) is assumed to be normally distributed; for example see McFarland et al.(1982). The inference is usually based on the QMLE (Quasi-Maximum Likelihood Estimation) of Bollerslev and Wooldridge (1992), which is valid when z_t is non-Gaussian.

This section of the paper represents an extensive analysis on the volatility properties of the returns of the daily Dubai oil prices by using the MA(1)-FIGARCH(1, d, 0) model with the normal distribution.[5] Estimation results of the above model for the returns are presented in Table 2. First of all, the estimated long memory volatility parameter (d) is estimated to be 0.96 for the Dubai oil prices, which is highly significant at the conventional significance level and is nonstationary with mean-reverting. The robustness of the estimate of the long memory volatility parameter in the returns of the daily oil prices strongly suggests that the long memory property seems to be an intrinsic feature in the oil markets. This finding of this paper is quite consistent with the works of Martens and Zein (2004) and Brunetti and Gilbert (2000).

5) Agnolucci (2008), Wei et al. (2010), Lee et al. (1995) and Mu (2007) used the GARCH type models to capture the high volatility process in the oil futures prices.

Table 2: MA(1)-FIGARCH (1, d, 0) model for the daily oil price returns

μ	0.1166
	(0.0515)
θ	-0.1488
	(0.0273)
d	0.9558
	(0.1028)
ω	0.0625
	(0.0565)
β	0.8883
	(0.0751)
ln(L)	-2859.891
m^3	-0.211
m^4	6.615
Q(20)	13.365
$Q^2(20)$	16.557

keys: QMLE asymptotic standard errors are in parentheses below corresponding estimates. ln(L) is the value of the maximized log likelihood. The m3 and m4 represent the skewness and the kurtosis of the residuals. The Q(20) and $Q^2(20)$ statistics are the Ljung-Box test statistics for serial correlation in the residuals and squared residuals.

On the other hand, the high excess kurtosis still remains even after the long memory property has been taken into account effectively. The estimated excess kurtosis in the residuals from the FIGARCH model with the normal distribution is found to be 6.62 for the Dubai oil prices, which are large enough to reject the normal distribution. The high excess kurtosis may be closely related to the occurrences of the jumps caused by the OPEC policy changes (Wang et al. 2008), the inventory reports by the Energy Information Administration (Mu 2007), or the unexpected economic news (Gronwald, 2011). Also, these jumps may be related to the significant changes in the oil demand resulted from the excess speculation in the oil futures markets (Davidson, 2008; Frankel and Rose, 2010). The excess speculative financial events in the oil markets concern expected future flows of the oil prices. These events may result in price changes well above the normal and lead to the level and volatility outliers generating the jumps. Thus, the simple FIGARCH model under the assumption of the normal distribution may not be appropriate to represent the returns well since the jumps are not accounted for.

Ⅲ. Jumps in the Oil Prices

This section is concerned with modeling the jumps and the high excess kurtosis in the daily oil price returns of the crude Dubai oil. For the purpose, this study employs the jump diffusion model proposed by Press (1967). The jump model has been proven to be useful tool for capturing the jumps triggered by unexpected events and news. As the oil markets are considered being subject to various economic and political influences, the jump model could be an appropriate method for modelling the oil prices providing interesting insights regarding the role of the jumps in the oil markets and which portion of the volatility can be attributed to the jumps. This jump model has subsequently been employed to capture the jumps in oil prices (Chan and Maheu, 2002; Askari and Krichene, 2008; Lee et al., 2010; Gronwald, 2011).

Since the efficient estimation of the parameters in continuous time processes is generally challenging, it is considered interesting to fit a normal mixture model in discrete time, taking advantage of the relatively simple formulation. Hence, this paper adopts the FIGARCH model with the jump diffusion process assuming that the oil returns are drawn from a mixture of the normal distribution and the jump process in order to model the jumps occurred in the returns appropriately. In particular, this paper uses this model combining with Bernoulli distribution which models the stochastic jumps in the returns of the daily oil prices. While Poisson process is generally used to model the stochastic jumps, the Bernoulli jump process could be more convenient in accounting for the jumps than the Poisson process since the Bernoulli process is much simpler in calculation without requiring the infinite sum and the truncation process.

For the Bernoulli distribution, the jump intensity (λ) is forced in the (0,1) interval and defined as λ = $[1 + \exp(j)]^{-1}$ assuning that it is constant over time for the simplicity. The jump size is given by the random variable v, which is assumed to be NID (Normally Independently Distribution)(υ, δ^2). Since the jumps and the long memory property have quite different in terms of the statistical and economic motivations, this paper adopts the estimation model that accounts for the two features simultaneously. The MA(1)-FIGARCH (1, d, 1) model with the Bernoulli jump process is,

$$y_{t,\,i} = 100^{*}[\mathit{In}(P_t) - \mathit{In}(P_{t-1})] = \mu + \lambda\nu + \theta\varepsilon_{t-1} + \varepsilon_t \tag{6}$$

$$\varepsilon_t \sim (1-\lambda)N(\lambda\nu,\, \delta^2) + \lambda N(\nu - \lambda\nu,\, \sigma_t^2 + \delta^2) \tag{7}$$

$$[1-\beta L]\sigma_t^2 = \omega + [1 - \beta L - \phi L(1-L)^d]\varepsilon_t^2 \tag{8}$$

Just as in Section 2, the returns of the daily oil prices are still specified as the MA(1) process. But, the difference is that the conditional mean process for the returns of the oil prices includes the jump intensity parameter (λ) which is constant and is drawn from the Bernoulli distribution with the mean of jump size (υ). And, the variable (δ^2) represents the variance of the jump distribution indicating the additional volatility caused by the jumps in the volatility process. The volatility process is the similar FIGARCH model as developed in Section II. The loglikelihood function for the model has the following form,

$$In(\zeta) = -(T/2)In(2\pi) + \Sigma In\{[(1-\lambda)/\sigma_t]*\exp[-(\varepsilon_t + \lambda v)^2/2\sigma_t^2] + [\lambda/(\sigma_t^2+\delta^2)^{1/2}]*\exp[-(\varepsilon_t - (1-\lambda)v)^2/2(\sigma_t^2+\delta^2)^2]\} \quad (9)$$

The asymptotic standard errors are calculated from the QMLE of Bollerslev and Wooldridge (1992) as in Section II.

Then this paper investigates the returns of the daily oil prices by the FIGARCH - Bernoulli jump diffusion model in order to examine the jumps in the conditional mean process and the long memory property in the conditional variance process. In particular, the jump process is included in order to reduce the influence of the jumps on the long memory volatility process. The estimation result from the FIGARCH model with the Bernoulli process is reported in Table 3.

Table 3: Estimated MA(1)-FIGARCH (1,d,1) Model - Bernoulli Jump process for the daily Dubai oil price returns

μ	0.2915
	(0.1540)
j	0.3216
	(0.1308)
υ	-0.4249
	(0.3129)
δ^2	2.4925
	(0.8331)
θ	-0.1547
	(0.0274)
d	0.6358
	(0.1160)
ω	0.2019
	(0.1262)
β	0.7494
	(0.0777)

φ	0.1710
	(0.0754)
ln(L)	-2,854.902
m^3	-0.036
m^4	3.504
Q(20)	12.271
$Q^2(20)$	16.591

Keys: the same as Table 1 except that the jump intensity of λ, where $\lambda = [1 + \exp(j)]^{-1}, 0<\lambda < 1$, and is specified to be generated by the Bernoulli distribution. The jump size is given by the random variable $v_t$whichisassumedtobeNID(ν, δ^2).

First of all, the estimated parameter (j) for the jump probability is found to be statistically significant at the conventional level of significance, implying that the daily oil prices contain the jumps in the conditional mean process. The jump intensities (λ) calculated from the estimated (j) is about 0.42 for the Dubai oil price returns suggesting that the corresponding implied number of the jumps for the daily oil prices is about 530. Some issues to be considered are how the jumps are interpreted and whether or not they correspond to public economic news in the oil markets. Without more detailed information, it is difficult to distinguish these issues.[6]

The estimated parameter (υ) which represents the impacts of the jumps on the mean process is found to be insignificant for the returns. This may be due to a general pattern of very quick and effective exchange rate conditional mean adjustment after the jumps.[7] However, the estimation results show that the jumps affect the volatility process (δ^2) in the returns very significantly and the effects are much greater than those on the mean process. The effects of jumps on

6) As a referee suggested, it could be possible to make the jump probability time –varying in the model. But, it will be left for future researches.

7) Some financial prices response to news very shortly within one or two minutes (Ederington and Lee, 1993; Flemming and Remelona, 1999; Andersen et al., 2002)

volatility process are more important and significant than the effects on the mean process.

Table 3 shows that the estimated long memory parameter (d) of the returns is found to be 0.64, and it is statistically significant. In particular, the long memory parameter in the FIGARCH model with the jump process is found to be much smaller than in the basic FIGARCH model without considering the jumps in Section II. This suggests that the jumps in the conditional mean process affect the long memory volatility property in the returns of the daily oil prices significantly and the greater long memory parameters can be caused especially when the jumps in the conditional mean process are not accounted for appropriately. These results show that conditional mean jumps, which otherwise might be spuriously associated with the additional volatility, can be fully accounted for with the mixture distribution. Thus, the greater long memory property seems to be related to asymmetric adjustments to conditional mean in response to the jumps. This is much more gradual and persistent than the conditional variance adjustments, and the jumps appear to be an important factor behind the long memory property in the volatility process of the returns of the oil prices.[8)]

Also, the LR (Loglikelihood Ratio) test for testing the null hypothesis of the basic FIGARCH model versus the Jump-FIGARCH model shows that the FIGARCH model is rejected at 5% significance level. And, the Ljung-Box test statistics presents that there is no evidence of serial correlation or instability in the conditional variance process of the daily oil price returns. These test statistics support the facts that the inclusion of the jump components generally improves the goodness of fit of the model and that the jump-FIGARCH is superior to the basic FIGARCH for modeling jointly the jumps and the long memory property in the

8) Andersen and Bollerslev (1998) and Andersen et al. (2002) presented that the jumps in the conditional mean process can drive the greater long memory property in the volatility process of the high frequency returns of foreign exchange rates

conditional variances of the daily oil price returns.

And, the estimation results show that the kurtosis statistics are reduced significantly after the jumps are accounted for. This confirms that the mixture distribution is generally better than the simple normal distribution. The reduced excess kurtosis further confirms that accounting for non-uniform flows of information can significantly improve the fit of the model. Thus, the FIGARCH model combined with the Bernoulli jump process appears to be quite appropriate for describing the conditional mean jumps, the long memory property and the excess kurtosis in returns of the daily oil prices.

Ⅳ. Conclusions

This paper examines the jumps and the long memory volatility in the daily crude oil prices focusing on the Dubai oil which is one of the most important input factors influencing on the Korean economy. First, the long memory property is found to have a significant impact on its volatility process in the returns of the daily oil prices. The FIGARCH model with the assumption of the normal distribution is found to provide a good model of the long memory property in the volatility process of the return series. And, the FIGARCH model persists for the analysis of the oil price returns in terms of the general appropriateness and robustness.

Then, this paper considers the jumps in the conditional mean process in the returns of the daily oil prices. The jumps may be caused by the OPEC policy, the inventory reports by the Energy Information Administration, the weather surprises, the unexpected economic news or excess speculative attacks in the oil markets. These jumps or large changes in the returns may affect the long memory volatility process in the returns, and can be better modeled using the FIGARCH model with the Bernoulli jump process. Such models are constructed to investigate the effects of the jumps on the long memory volatility property in the return of the daily oil prices.

The FIGARCH-Bernoulli jump process model is found to be more appropriate for representing the jumps in the conditional mean process and the long memory property in the volatility process of the oil returns. In particular, the estimated long memory parameters estimated from the FIGARCH model with the Bernoulli jump process are found to be much smaller than that from the basic FIGARCH model without considering the jumps. This presents strong evidence that the specification of the conditional mean process may distort the long memory volatility properties of the oil returns if the jumps are not considered appropriately and that a considerable part of the long memory property is attributed to the jumps inducing higher long memory parameters.

Thus, this paper shows the usefulness and the superiority of the Jump-FIGARCH model relatively to available alternative modeling strategies for the dynamics of the crude oil prices. In particular, the findings of this paper could be helpful for investors and policy makers to manage the risks and design the portfolio strategy in crude oil markets if they can predict the movement of crude oil prices correctly by using the more accurate forecasting of the volatility dynamics with the long memory dependency and the jumps. Consequently, it is hoped that the findings of this paper may be helpful in the better understanding the dynamics of the crude oil prices and in developing further empirical investigations in the oil markets such as tests for market efficiency, risk management and portfolio management.

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◎ References ◎

Agnolucci, P. 2008. "Volatility in crude oil futures: a comparison of the predictive ability of GARCH and implied volatility models." *Energy Economics* 31: pp.316-321.

Alvarez-Ramirez, J., Alvarez, J. and Rodriguez, E. 2008. " Short-term predictability of crude oil markets: a detrended fluctuation analysis approach." *Energy Economics* 30: pp.2645-2656.

Andersen, T.G. and Bollerslev, T. 1998. "Deutsche mark - dollar volatility: intraday activity patterns, macroeconomic announcements and longer run dependence." *Journal of Finance* 53: pp.219-265.

Andersen, T.G., Bollerslev, T., Diebold, F. X. and Vega, C. 2002. "Micro effects of macro announcements: real-time price discovery in foreign exchange." NBER Working Paper, No. W8959.

Askari, H. and Krichene, N. 2008. "Oil price dynamics (2002-2006)." *Energy Economics* 30: pp.2134-2153.

Bacon, R. 1991. " Modelling the price of oil." *Oxford Review of Economic Policy* 7: pp.17-34.

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

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

Brunetti, C. and Gilbert, C.L. 2000. "Bivariate FIGARCH and fractional cointegration." *Journal of Empirical Finance* 7: pp. 509-530.

Chan, W.H. and Maheu, J.M. 2002. "Conditional jump dynamics in stock market returns." *Journal of Business and Economic Statistics* 20: pp.377-389.

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: pp. 342-363.

Chung, S-K. 2008. "Explaining asymmetries and long memory for hedge effectiveness in China Aluminum and fuel oil futures markets," *Journal of Financial Engineering* 7: pp.129-158.

Davidson, P. 2008. "Crude oil prices: market fundamentals or speculation?" *Challenge* 51:pp. 1110-1118.

Ederington, L.H. and Lee, J.H. 1993. "How markets process information: News releases and volatility." *Journal of Finance* 48: pp.1749-1778.

Elder, J. and Serletis, A. 2008. "Long memory in energy futures prices." *Review of Financial Economics* 17: pp. 146-155.

Flemming, M.J. and Remolona, E.M. 1999. "Price formation and liquidity in the U.S. Treasury market: The response to public information." *Journal of Financial Economics* 19: pp.3-29.

Frankel, J.A. and Rose, A.K. 2010. "Determinants of agricultural and mineral commodity prices." in: Fry,, R., Jones, C. and C. Kent (eds), *Inflation in an Era of Relative price Shocks*, Sydney.

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: pp. 399-421.

Gronwald, M. 2011. "A characterization of oil price behavior-evidence from jump models." CESifo Working Paper No.3644.

Jin, H. J. and Frechette, D. 2004. "Fractional integration in agricultural futures price volatilities." *American Journal of Agricultural Economics* 86: pp.432-443.

Lee, K., Ni, S. and Ratti, R. 1995. "Oil shocks and the macroeconomy: the role of price variability." *The Energy Journal* 16: pp.39-56.

Lee, Y.H., Nu, H.N. and Chiou, J.S. 2010. "Jump dynamics with structural breaks for crude oil prices." *The Energy journal* 24: pp.557-576.

Martens, M. and Zein, J. 2004. "Predicting financial volatility: high frequency time-series forecasts vis-à-vis implied volatility." *Journal of Futures Markets* 24: pp.1005-1028

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

Mu, X. 2007. "Weather, storage and natural gas price dynamics: fundamentals and volatility." *Energy Economics* 29: pp.46-63.

Press, J. 1967. "A compound events model for security prices." *Journal of Business* 40: pp.317-335.

Rapaport, A. 2012. "Supply and demand shocks in the oil market and their predictive power." Working Paper No. 12-52. The University of Chicago Booth School of Business.

Vo, M.T. 2009. "Regime-switching stochastic volatility: evidence from the crude oil market." *Energy Economics* 31: pp.779-788.

Wang, T., Wu, J. and Yang, J. 2008. "Realized volatility and correlation in energy futures markets." *Journal of Futures Markets* 28: pp.993-1011.

Wei, Y., Wang, Y. and Huang, D. 2010. "Forecasting crude oil market volatility: further evidence using GARCH-class models." *Energy Economics* 32: pp.1477-1484.

Wirl, F. 2008. "Why do oil prices jump (or fall)?" *Energy Policy* 36: pp.1029-1043.

요 약

일별 원유 현물가격의 점프현상과 장기기억 변동성 특성: 두바이 원유 중심으로*

한영욱**

본 논문은 일별 두바이 원유가격 자료를 이용하여 국제 원유 시장에서 불안정적인 흐름과 지속적인 변동성을 발생시키는 본질적인 속성들 가운데 점프현상과 장기기억 변동 특성을 중심으로 일별 원유 가격의 최근 변화에 대해 파악한다. 먼저 본 논문은FIGARCH모형을 이용하여 일별 원유 가격 수익률의 변동성 과정에서 나타나는 장기기억 특성에 대한 통계적 증명을 밝힌다. 또한 본 논문에서는 일별 원유 수익률의 조건부 평균과정 에서 현저한 점프현상이 있음을 발견하고 이를 위해 Bernoulli 점프 현상을 이용한 정규혼합 분포를 적용한다. 이러한 분서결과를 통해 일별 원유가격의 수익률에는 변동성 과정에서 장기기억 특성이 존재하며, 또한 점프현상이 장기기억 현상과 밀접한 관련이 있으며, 특히 이러한 점프현상들이 장기기억 특성에 상당한 부분을 기여하고 있으며 이를 보다 더 심화시킬 수 있다는 것을 제시한다.

핵심단어: 일별 두바이 원유 가격, 점프현상, FIGARCH 모형, Bernoulli 과정, 장기기억 변동 특성.

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