Energy Futures Volatility, Trading Activity, and Regime Switching*

Nicholas Rueilin Lee**

Abstract

This paper examines asymmetric impacts of various percentages of futures trading activities on price volatility for energy futures of crude oil and heating oil at the New York Mercantile Exchange (NYMEX). Due of turbulent energy futures prices from the early 2000s, this paper applies threshold autoregressive model to determine structure changes, and the sample prior to and beginning 2000s are also analyzed separately. Results for periods beginning 2000s strongly confirm findings by Bessembinder and Seguin (1993) of a significant positive relation between unexpected volume and volatility and a significant negative relation between expected open interest and volatility. We further find stronger impacts of extremely higher or lower unexpected volume for both two and extremely higher unexpected open interest for heating oil on the volatility since 2000s whereas smaller impacts are found prior to 2000s. Hence, it provides more valuable insights on varying relations of volatility, volume, and open interest in energy futures markets throughout the time.

Keywords: Futures Volumes, Open Interest, Volatility, Asymmetry, Qunantiles Analyses

JEL Classification: Q40, G10, G12, C10

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** Assistant Professor, Department of Finance, Chaoyang University of Technology. Corresponding Author. Tel: (04)23323000 ext. 4490, Email: rllee@cyut.edu.tw.

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I. Introduction

Energy price volatilities are of overriding concern.[1] The higher the price volatility, the greater is the uncertainty facing the market. Fluctuations in energy futures prices are caused by supply and demand imbalances arising from events like wars, economic crises, changes in political regimes, unexpected weather patterns, formation/ breakdown of trade agreements etc. Moreover, the energy futures markets experienced periods of high volatility only during the Middle East conflict in 1990-1991, during the Asian currency crisis in 1997-1998, during Venezuelan oil strike in 2002, and during the invasion of Iraq in 2003. In short, energy futures prices are volatile, and volatility itself varies over time.

Prior studies discuss whether futures trading activities affect volatility. Although several studies examine the impact of futures trading on the volatility, mixed results are found.[2] Some studies maintain there is no discernible volatility effect. Others find evidence of a volatility increases, implying that volatility increased after the introduction of futures trading began, and

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[1] Crude oil futures' prices have rapidly increased from around US$30/barrel (bl) in 2004 to being close to US$70/bl in September 2005, equivalent to an increase of about 133 percent.

[2] These include Froewiss (1978) and Figlewski (1981) for GNMA securities; Edwards (1988), Kawaller et al. (1990), Bessembinder and Seguin (1992), and Chatrath et al. (1998) for S&P 500 Index; Antoniou and Holmes (1995) for FTSE 100 Index; Bae et al. (2004) for Korean index; Lee and Ohk (1992) and Chang et al. (1999) for Nikkei Index; Bessembinder and Seguin (1993) and Fung and Patterson (1999) for currency market; Simpson and Ireland (1985) for Treasury bill market. A consensus based on their findings remains elusive.

some evidence of a decrease indicates that an increase in futures volume leads to a decrease in volatility.

However, few studies examine the relation of two variables for energy products. Herbert (1995) finds that volume may explain the volatility although Nainar (1993) shows that weekly volatility tends to increase with petroleum futures trading. Herbert also discovers that past levels of volume influence current price volatility but that past variability has much less of an influence on current levels of trading. Liew and Brooks (1998) investigate the determinants of daily returns and volatility in the Kuala Lumpur crude palm oil futures market while Foster (1995) finds that there is contemporaneous positive relation between volume and volatility for crude oil futures. Liew and Brooks find significant evidence of month and open interest effects in returns and also find strong evidence of daily, monthly, yearly, volume and open interest effects in volatility. In contrast, Fleming and Ostdiek (1999) examine effects of energy derivatives trading on the crude oil market and find that derivative securities increase volatility and can have a destabilizing effect on the underlying market. Their analysis reveals a strong inverse relation between the open interest in crude oil futures and spot market volatility.

Subsequent research divides futures trading activity into expected and unexpected components, and focuses on asymmetries of futures trading and volatility, with mixed evidence. Bessembinder and Seguin (1993) examine eight currency, interest rate, and commodity futures and find that spot volatility is positively related to unexpected volume and negatively related to expected open interest. Furthermore, they present that spot volatility decreases when unexpected open interest increases. It indicates that futures tradings increase the depth and liquidity of underlying asset market, mitigating the impact of volume shocks on volatility. On the other hand, Bessembinder and Seguin (1992) provide some reconciling evidence that volatility is positively related to unexpected trading activity of the S&P 500 index futures, but negatively to expected trading activity. Fleming and Ostdiek (1999) examine the effects of energy derivatives trading on the crude oil market. They find that futures volume increases volatility and can have a destabilizing effect on the underlying market. Their analysis reveals a strong inverse relation between open interest and spot volatility. Furthermore, similar results are obtained when splitting volume and open interest into expected and unexpected components. Specifically, when open interest is greater, the volatility shock associated with a given unexpected increase in volume is much smaller.

This paper examines energy futures for crude oil and heating oil at the New York Mercantile Exchange (NYMEX) and its relation of futures trading activities and price volatility. In addition, this paper extends the work of Fleming and Ostdiek (1999) to examine asymmetries in volume-volatility and open interest-volatility relations for energy futures, respectively.[3] Finally, we use various percentages of futures trading activities to consider asymmetries of this relation. Due of variability in energy futures prices from the early 2000s, this paper applies the threshold autoregressive model (switching regression) to determine the structure changes, and the sample prior to and beginning 2000s are also analyzed separately.

For our analyses of energy futures markets, there are at least three reasons we might expect results that differ from past research. First, in general, there is little research regarding physical commodity derivatives, and this research is primarily focused on energy futures contracts. Second, given these possible reasons resulting from the imbalance of demand and supply in energy futures markets, we confirm whether structure change exists.[4] Our findings provide interesting insights on the relation of volatility and futures trading in energy markets, especially for a surge in energy prices across markets. Finally, our particular thrust of this effort is to investigate an asymmetry in relation of futures trading and volatility. Specifically, by comparing the various percentages of futures trading shocks, our findings further shed lights on impacts of futures trading on volatility across energy futures markets.

Results for the periods beginning 2000s strongly confirm the finding by Bessembinder and Seguin (1993) of a significant positive relation between unexpected volume and volatility and a significant negative relation between expected open interest and volatility. We further find that the impact of extremely higher or lower unexpected volume shocks for both markets

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[3] Fleming and Ostdiek (1999) only examine the relation of volatility and futures trading for crude oil futures, not considering heating oil futures.

[4] For example, OPEC may find it profitable to intervene in the futures market to influence the production decisions of their competitors in the spot market.

and extremely higher unexpected open interest for heating oil market on the volatility tends to be stronger since 2000s. In contrast, relations of volatility, volume, and open interest for both markets are found to be smaller prior to 2000s.

The organization of the rest of the paper is as follows. The next section reviews methods developed by Bessembinder and Seguin (1993) and explains the data used, and section 3 summarizes the estimated results. Finally, section 4 concludes the article.

II. Methodology and Data

A. Structure shifts

To confirm the existence for structure change, we seek to examine the temporal variability in settlement price (p_t) of the nearby contract without imposing a set of prior beliefs concerned with the time such changes occurred. This paper applies the regime switching models (or threshold autoregressive model, TAR) introduced by Goldfeld and Quandt (1973, 1976) to detect possible shifts in energy futures prices. Consider the simplified case of a model with two regimes.[5]

$$p_t = \begin{cases} \alpha_1 + \beta_1 \cdot p_{t-1} + e_1 & t \le t_0 \\ \alpha_2 + \beta_2 \cdot p_{t-1} + e_2 & t > t_0 \end{cases} \tag{1}$$

5 This method is also employed by Tsay (1989), Shawky and Marathe (1995), and Cheng (1996, 1997). On the other hand, the time series $\{p_t\}$ is assumed to follow a random walk with a drift with two regimes. Regardless of α, the t ratio for testing $\beta = 1$ is asymptotically normal (Tsay, 1989). The error terms are assumed to be an i.i.d. white noise sequence conditional upon the history of the time series.

where e_1 and e_2 are distributed as $N(0, \sigma_1^2)$ and $N(0, \sigma_2^2)$ respectively and $\operatorname{cov}(e_1, e_2) = 0$.

This model assumes that the border between the two regimes is given by a specific value of the threshold values, t_0. Next, when estimating the parameters of the regimes that produce the data, the likelihood function conditional on t_0 is as follows.

$$L(\alpha_1, \alpha_2, \beta_1, \beta_2, \sigma_1^2, \sigma_2^2 \mid t_0) = (2\pi)^{-N/2} \cdot \sigma_1^{-t_0} \cdot \sigma_2^{-(N-t_0)} \cdot$$
$$\exp\left\{-\frac{1}{2\sigma_1^2}\sum_{t=1}^{t_0}(p_t - \alpha_1 - \beta_1 \cdot p_{t-1})^2 - \frac{1}{2\sigma_2^2}\sum_{t=t_0+1}^{N}(p_t - \alpha_2 - \beta_2 \cdot p_{t-1})^2\right\} \tag{2}$$

The maximum likelihood ratio, $-2\times\log(L_{t0} / L_{t0+1})$, is then used to identify the number of regimes operating during the analysis period. Specifically, the null hypothesis of one regime is tested against the alternative of two regimes. Asymptotically, this ratio is distributed as x^2 with degrees of freedom equal to the number of restrictions under the null hypothesis.

B. The impact of futures trading activity on volatility

a. Basic model

This article follows Bessembinder and Seguin (1993) to iterate and estimate between a conditional mean and a conditional volatility equation of the form.

$$R_t = \alpha + \sum_{j=1}^{n}\gamma_j \cdot R_{t-j} + \sum_{i=1}^{4}\rho_i \cdot d_{it} + \sum_{j=1}^{n}\pi_j \cdot \hat{\sigma}_{t-j} + U_t \tag{3}$$

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n}\omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n}\eta_i \cdot d_{it} + \sum_{j=1}^{n}\beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m}\mu_k \cdot A_{kt} \tag{4}$$

where R_t is the percentage change in the settlement price of the nearby futures contract on day *t*. $\hat{\sigma}_t$ is the conditional volatility. $d_{it}(i=1,\cdots,4)$ are day-of-week dummy variables.[6] $A_{kt}(k=1,\cdots,m)$ measure the futures trading activities.[7]

Following Schwert and Seguin (1990), transformed equation is as follows.[8]

$$\hat{\sigma}_t = |\hat{U}_t|\sqrt{\pi/2} \tag{5}$$

The method for estimating $\hat{\sigma}_t$ will be explained below. As recommended by Davidian and Carroll (1987), Schwert and Sequin (1990), and Beseembinder and Sequin (1993), equations (3) and (4) are estimated sequentially. Equation (3) is first estimated without lagged volatilities, using ordinary least squares (OLS). The obtained residuals are then transformed to the volatility applying equation (5). Given the obtained volatilities, equation (4) is estimated. Fitted values from equation (4) are then employed as regressors in reestimating (3). Finally, equation (4) is reestimated by using residuals from the consistent estimation of equation (3). Moreover, to avoid biased standard errors in estimating equation (4), White (1980) standard errors are used to obtain correct estimates. Additionally, similar method proposed by White (1980) standard errors is also used when estimating succeeding equations (6), (7), and (8).

Equation (4) enables us to test several hypotheses. First, we can assess the extent of

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6 Specifically, d_{1t} takes one when day t is Monday and zero otherwise, d_{2t} takes one when day t is Tuesday and zero otherwise, and so on. These dummy variables capture differences in mean and standard deviation by day of the week (see for example, French, 1980; French and Roll, 1986).

7 Bessembinder and Seguin (1993) partition futures volume and open interest into expected and unexpected components and use them as trading activity variables, $m=4$, to take into account the possibility that expected and unexpected shocks may have a different impact on volatility.

8 This transformation produces the unbiased estimates of conditional returns standard deviations (see Bessembinder and Seguin, 1993).

aggregate effects of lagged unexpected return on volatility. It helps to capture this asymmetry in volatility. Second, we examine the evidence of the day-of-week effect. Additionally, we also discuss volatility clustering.[9] The degree of persistence may be expected to underestimate since past expected and unexpected futures trading activities are related to past volatilities.

Finally, we examine the relationships between volatility and both expected and unexpected futures trading activities. Negative (positive) coefficient for the effect of expected volume on volatility is anticipated to a(n) decrease (increase) in volatility as expected volume increases, suggesting that it stabilizes (destabilizes) the market. Moreover, negative (positive) coefficient for the effect of expected open interest on volatility is anticipated to a(n) decrease (increase) in volatility as expected open interest increases, suggesting that deeper market depth lessens (enhances) the market.

On the other hand, we also need to incorporate the impact of both volume shocks and open interest shocks on volatility. For instance, volume shocks capture a(n) increase (decrease) in volatility whereas open interest shocks reflect a(n) decrease (increase) in volatility. It suggests that unanticipated changes in either volume or open interest are expected to affect the stabilization or market depth.

Therefore, it should shed valuable lights on the simultaneity relationships of volatility and both expected and unexpected futures trading activities across energy futures markets.

b. Asymmetry in the effects of volumes (open interest) shocks

Following Bessembinder and Seguin (1993), we estimate the model allowing the effects of unexpected volume and open interest on volatility to vary with the sign of shocks. Specifically, equation (4) is replaced by

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt}$$

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[9] Nelson (1991) documents that negative return shocks have a greater effect on subsequent volatility in stock markets.

$$+\vartheta \cdot Voldum_t \cdot UV_t + \chi \cdot OpIndum_t \cdot UOI_t \tag{6}$$

where $Voldum_t$ is the dummy variable that takes one when unexpected volume (UV) on day t is positive and zero otherwise. $OpIndum_t$ is the dummy variable that takes one when unexpected open interest (UOI) on day t is positive and zero otherwise.

Equation (6) enables us to focus on asymmetry in the effects of volumes (open interest) shocks and confirms the existence of asymmetry for the futures trading activities-volatility relation. As for the volume-volatility relation, by following Bessembinder and Seguin (1993), the coefficient associated with the unexpected series represents the marginal impact of a negative shock on volatility while the marginal effect of a positive shock can be estimated by adding the coefficients associated with the unexpected series and the product of the unexpected series and the indicator variable. We further compare the magnitude of the asymmetry across energy futures markets by using the method proposed by Bessembinder and Seguin (1993) that the asymmetry is measured by the ratio of estimated coefficient associated with positive shocks (which are the sum of the unexpected volume coefficient plus the cross-product coefficient) to the estimated coefficient associated with negative shocks (which is the unexpected volume coefficient). This finding will provide insights on the asymmetry in the effects of volumes shocks.

However, the asymmetry associated with open interest takes a different form. The sum of estimated coefficients associated with unexpected open interest and estimated coefficients associated with the cross-products measures the effect of an unanticipated increase in open interest. Thus, the sum of the two is positive (negative), indicating an unanticipated increase in open interest is related to higher (lower) volatility. It will confirm the evidence of the asymmetry in the effects of open interest shocks.

c. Asymmetry in the effects of percentiles of volumes (open interest) shocks

To further examine the asymmetry in effects of various percentiles of the distributions of volumes and open interest shocks, we let $UA_t^{(q)}(UA_t^{(1-q)})$ be the $q^{-th}((1-q)^{-th})$ quantile unexpected in futures trading activity.[10] $LUA_t^{(q)}(RUA_t^{(1-q)})$ equals to the magnitude of unexpected futures trading activity if unexpected futures trading activity on day t is smaller (larger) than the q^{-th} quantile of the distribution and zero otherwise.

We estimate an asymmetric equation, including simultaneously right-tail quantile levels, with the following asymmetric equation.

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt} + \sum_{q \in Q} \chi_q^{RUA} \cdot RUA_t^{(1-q)} \quad (7)$$

Equation (7) allows us to examine the sensitivity of the asymmetric relation to the magnitude of positive unexpected futures trading activities quantile shocks. Our findings are expected that the futures trading activities-volatility relation is dominated by extremely positive volume and open interest quantile shocks.

Eventually, we include both tails of the distribution of futures trading activity, yielding symmetric equation.

$$\begin{aligned} \hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt} \\ + \sum_{q \in Q} \vartheta_q^{LUA} \cdot LUA_t^{(q)} + \sum_{q \in Q} \chi_q^{RUA} \cdot RUA_t^{(1-q)} \end{aligned} \quad (8)$$

Equation (8) allows us to examine the sensitivity of the symmetric relation to the magnitude of the positive and negative unexpected futures trading activities quantile shocks. In addition to the impact of extremely positive volume and open interest quintile shocks on volatility, our findings are also expected that extremely negative volume and open interest quantile shocks have heterogeneous effects on volatility. That is, symmetric relations are more pronounced at the extremely positive and negative volume and open interest quantile shocks.

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[10] Let $F(x) = prob(y \le x; (x, y) \in A_t)$ denote the empirical cumulative distribution function of $A_t : A_t^{(q)}(A_t^{(1-q)})$ is such that $F(A_t^{(q)}) = q(F(A_t^{(q)}) = 1 - q)$.

Our findings will provide differences in the impact of equally large positive and negative surprise futures trading activities shocks on the volatility.

C. Data used and variable defined

This study examines impacts of the expected and unexpected components of energy futures trading activities on futures price volatility. Energy futures contracts at New York Mercantile Exchange (NYMEX) are obtained from Pricedata Company and comprised two energy futures contracts for crude oil and heating oil. We select futures volumes and open interest summed across all outstanding maturities (Bessembinder and Seguin, 1993). Our daily data spans the period from the introduction of energy futures through August 2005.[11]

This paper follows Fung and Patterson's (1999) method used a 100-day backward moving average to define the measure of futures volumes. This approach is also applied by Campbell et al. (1993), and different with Bessembinder and Segiun (1992, 1993) and Fleming and Ostdiek (1999). This volume measure is defined as:

$$V_t = \frac{VT_t}{\frac{1}{100}\sum_{i=1}^{100} VT_{t-i}} \tag{9}$$

where VT_t is the log of futures volumes at time t. Futures volumes can be treated as information about changes and agreements in investors' expectations (Bessembinder and Seguin, 1993). The rational is that daily volume traded is assumed largely to reflect speculation, as hedgers' transactions comprise relatively minor proportions of total daily volumes traded.

The level of market depth may affect the speed and ease of transactions, and represents a measure of trading activity that reflects the willingness of traders to risk capital in the presence of price volatility in the futures contracts. Moreover, open interest largely captures hedging

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[11] In 1978 energy futures and options first began trading when heating oil futures were introduced at the NYMEX. In 1983 NYMEX crude oil futures were introduced.

positions because open interest reflects longer than intraday positions.[12] We use open interest as a proxy for market depth and apply the transformation procedure used for volume measure. This procedure is important because it tends to lessen the mechanical links between volume and open interest in the actual trading. Specifically, increases or decreases in open interest lead to more contracts traded, indicating that changes in open interest tend to stimulate volume.

We then partition the each series into expected and unexpected components using ARIMA models. Thus, this step yields two series of one-step-ahead forecast errors.

$$UA_{ijt} = A_{ijt} - E[A_{ijt} \mid A_{ijt-\tau}] \tag{10}$$

where $i = 1, 2$ and $j = V, OI$ as V notes futures volume and OI represents open interest.

The unexpected component of each series, UA_{ijt}, interpreted as daily activity shock. The expected component of each series (which is roughly equal to the difference between the actual series and the unexpected component, $A_{ijt} - UA_{ijt}$) reflects predicted activity but highly variable across days.

III. Results

A. Variability in energy futures prices

Figure 1 shows a time series plot of energy futures prices. Although the early 1990s were a time characterized by both large oil price increases and large oil price decreases during the Persian Gulf crises, oil futures prices were fairly constant up to the early 2000s after which

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[12] See Rutledge (1979), Leuthold (1983), Bessembinder and Seguin (1993), and Chang et al. (2000).

time they exhibit an upward trend.[13] Additionally, heating oil futures prices are also presented similar patterns.

The estimation period for this study covers the somewhat turbulent time of the 2000s. Consequently, it is important to check the data for structural breaks. Table 1 reports results of switching regression identifying the most likely switch date and estimating two-regime parameters. Note that the null hypothesis of a single regime (no switch) is rejected in favor of two regimes specification for all energy futures contracts. In addition, our finding seems to suggest that the beta estimates are larger in the second regime then the first regime, indicating the somewhat turbulent time of the 2000s.

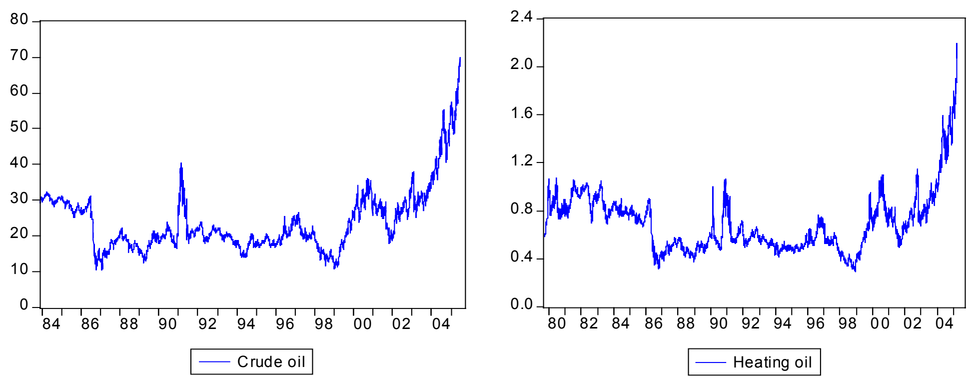

Figure 1 Daily settlement price for crude oil and heating oil futures on NYMEX

[13] In the study of Kohl (2002), oil prices plunged to around $10/barrel in late 1998 and early 1999, then recovered and soared above $30/barrel in 2000. After seriously misjudging the oil market in 1997–98 and contributing to an oil price collapse, OPEC rallied in 1999–2000 and successfully pushed prices upward but overshot its target. In the first half of 2001 OPEC maintained high but more stable oil prices. Later in the year OPEC struggled to manage falling prices set off by a global recession made worse by the attacks of September 11 and the war on terrorism.

Table1 Goldfeld-Quandt threshold autoregressive (TAR) models results identifying the most likely switch dates and estimating two-regimes parameters

$$p_t = \begin{cases} \alpha_1 + \beta_1 \cdot p_{t-1} + e_1 & t \le t_0 \\ \alpha_2 + \beta_2 \cdot p_{t-1} + e_2 & t > t_0 \end{cases}$$

	Crude oil	Heating oil
Switching date (t_0)	2000/2/7	2000/1/12
LR	746.99**	645.89**
α_1	0.0869**	0.0029**
β_1	0.9958**	0.9954**
α_2	0.0048**	0.0004**
β_2	1.0007**	1.0007**

Note: Likelihood ratio (*LR*) is the test statistic of the hypothesis of no-switching. ** indicates significant at the 1% level, and * indicates significant at the 5% level.

B. Preliminary analyses

Table 2 provides descriptive statistics, mean, maximum, minimum, and standard deviation for returns, absolute returns, volumes, and open interest. The violent market is heating oil with standard deviation exceeding 1.72% per day, following crude oil (1.54%). Particularly, these markets exhibit higher variability in energy futures price in the second regime than the first regime. On the other hand, the largest change in the long run movement in volume is heating oil with 1.0171, while the smallest one is crude oil, with 1.0056. Similar results are obtained when considering market depth.

However, when comparing the change in the long run movement in volume and open interest series in the first and second regime, results reveal that the series in the second regime are slight lower than first regime. These findings support that, in the second regime, there is little change in the long run in volume, and it also influences order flow of the futures transactions and willingness of traders to risk their capital.

Table 2 Summary statistics for energy futures markets

		Statistics	*R*	|*R*|	*V*	*OI*
Crude oil	Full	Mean	0.0148%	1.5372%	1.0056	1.0050
		Maximum	14.0330%	38.4070%	1.2787	1.0962
		Minimum	−38.4070%	0.0000%	0.7527	0.9788
		Std. dev.	2.2535%	1.6478%	0.0376	0.0136
		ADF	−75.59 **	−2.52 *	0.0500	0.3800
	First	Mean	−0.0008%	1.4408%	1.0069	1.0063
		Std dev.	2.2053%	1.6695%	0.0411	0.0150
	Second	Mean	0.0612%	1.8300%	1.0015	1.0012
		Std dev.	2.3938%	1.5435%	0.0232	0.0060
Heating oil	Full	Mean	0.0185%	1.7216%	1.0171	1.0130
		Maximum	29.4480%	39.0940%	2.7286	1.5761
		Minimum	−39.0940%	0.0000%	0.0000	0.9275
		Std. Dev.	2.6602%	2.0280%	0.1227	0.0626
		ADF	−65.35 **	−6.59 **	−1.9300	−1.9000
	First	Mean	0.0022%	1.6176%	1.0215	1.0164
		Std dev.	2.5485%	1.9691%	0.1373	0.0699
	Second	Mean	0.0810%	2.1084%	1.0011	1.0005
		Std dev.	3.0398%	2.1905%	0.0265	0.0112

Notes: 1. ** indicates significant at the 1% level, and * indicates significant at the 5% level.

2.Volume (V) and open interest (OI) series are removed the linear and nonlinear trend.

The final column reports modified Dickey-Fuller test statistics for the presence of unit roots in returns, absolute returns, volume, and open interest. The existence of a unit root is not rejected for all volume and open interest series. After removing time trend all volume and open interest series, the existence of a unit root is rejected.[14]

C. Conditional mean and variance equation

Equations (3) and (4) are estimated for each of two contracts. Results of estimating the conditional mean equation (3) are presented in Table 3. For full sample, all day-of-the-week dummies are insignificant for crude oil and heating oil. Lagged volatilities are positive and jointly insignificant for crude oil but negative and significant for heating oil. This result contrasts with Bessembinder and Seguin (1993) who find a significant positive relation between the conditional mean and lagged volatilities, but it is accordant with Nelson (1991). Moreover, lagged unexpected returns have significant explanatory power. To measure the linear association between adjacent residuals from a regression model, we use the Durbin-Watson statistic (DW). Results suggest no serial correlation.

To understand whether variability in energy futures prices may have altered the aforementioned analyses, this study conducts sub-sample analyses to confirm the stability of results. Prior to variability in energy futures prices, results in the first regime are similar to those for full sample. In the second regime, there exist significant day-of-week effects for crude oil and heating oil. Lagged unexpected returns for crude oil have insignificant explanatory power while significant for heating oil.

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[14] Since previous studies have reported strong evidence of time trend in trading volume series (see Gallant et al., 1992; Andersen, 1996; Chen et al., 2001), we test trend stationarity in trading activities by regressing the series on a deterministic function of time. We then use the de-trended futures trading as the new proxy, and find the null hypothesis that detrended futures trading series is nonstationary is strongly rejected. Such a result substantiates that the detrended futures trading is stationary.

Table 3 Autoregressive model for daily energy futures returns

$$R_t = \alpha + \sum_{j=1}^{n} \gamma_j \cdot R_{t-j} + \sum_{i=1}^{4} \rho_i \cdot d_{it} + \sum_{j=1}^{n} \pi_j \cdot \hat{\sigma}_{t-j} + U_t$$

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
Intercept	0.0005	–0.0008	0.0094*	0.0019	0.0016	0.0025
Monday	–0.0016	–0.0002	–0.0055**	0.0000	0.0003	0.0001
Tuesday	–0.0007	0.0001	–0.0041*	0.0006	0.0009	0.0020
Wednesday	–0.0008	0.0008	–0.0055**	0.0005	–0.0005	0.0027
Thursday	0.0005	0.0015	–0.0026	0.0027*	0.0021	0.0064*
$\sum\pi$	0.0113	0.0172	–0.2200	–0.1153**	–0.1087	–0.1483
$\sum\gamma$	–0.1581**	–0.1596**	–0.1802	–0.3635**	–0.3976**	–0.2848**
Adj-R^2	0.0053	0.0062	0.0042	0.0385	0.0448**	0.0169
DW	2.0010	2.0010	2.0020	2.0010	2.0000	1.9850

Note: ** indicates significant at the 1% level, and * indicates significant at the 5% level.

Results of estimating the volatility equation (4) are presented in Table 4. For full period, dummy variables on day-of-week effects are significant. Coefficients estimates for unexpected volume are significant and positive for both two markets, but coefficients estimates for unexpected open interest are insignificant and negative for both two products. In contrast, coefficient estimate for unexpected volume is positive and larger than that for expected volume, demonstrating that unexpected volume shock have a positive and larger effect on volatility. These results are consistent with Bessembinder and Seguin (1993) and Karpoff (1987).

Coefficients estimates for expected open interest are significant and negative for both markets, suggesting that Bessembinder and Seguin (1993) argue that expected open interest is positively related to the number of traders and an increase in number of traders enhances market depth and lessens volatility. Furthermore, an insignificant negative coefficient of unexpected open interest for crude oil and heating oil is inconsistent with Fleming and Ostdiek

(1999) arguing that an increase in open interest during the trading day lessens the impact of an open interest shock on volatility.

Table 4 Regressions of estimated daily futures returns standard deviations on expected and unexpected trading activity

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt}$$

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
Intercept	0.0057**	0.0049**	0.0162**	0.0063**	0.0047**	0.0150**
Monday	0.0038**	0.0044**	0.0016	0.0037**	0.0046**	0.0017
Tuesday	−0.0028**	−0.0022*	−0.0081**	−0.0007	−0.0001	−0.0048**
Wednesday	−0.0006	−0.0011	−0.0034*	0.0019*	0.0016	−0.0007
Thursday	−0.0010	−0.0012	−0.0020	0.0002	0.0003	−0.0020
EV	−0.0047	−0.0015	−0.0717	0.0186**	0.0161*	0.0663
UV	0.2240**	0.1987**	0.3949**	0.0782**	0.0580**	0.3380**
EOI	−0.1150**	−0.1047**	−0.2511**	−0.0356**	−0.0360**	−0.2320**
UOI	−0.1940	−0.2042	0.9911*	0.0128	0.0312	0.3092
$\sum\beta$	0.7095**	0.7334**	0.3803**	0.6525**	0.7028**	0.4509**
$\sum\omega$	0.0051	0.0205	−0.1739**	0.1191**	0.1499**	−0.0320
Adj-R^2	0.2392	0.2595	0.1955	0.1758	0.1991	0.1544
DW	1.9940	1.9900	2.0190	1.9880	1.9920	1.9650

Notes: 1. ** indicates significant at the 1% level, and * indicates significant at the 5% level.
2. White (1980) standard errors are used.

The sums of the estimated coefficients associated with 10 lagged volatilities for both markets are positive and significant, exhibiting significant persistence in volatility. The sums of estimated coefficients associated with 10 lagged unexpected returns are insignificant for crude oil but significant for heating oil. Our findings are partial consistent with Bessembinder and Seguin (1993), where estimated coefficients on lagged unexpected returns are insignificant for agricultural, metal, currency, and bond futures.

To confirm the stability of previous analyses, we compare results in the first regime with the second regime in Table 4. Our finding indicates that, although there exists the day-of-effect for both markets, the coefficient of Monday is significant in the first regime, and becomes insignificant in the second regime. For significant persistence in volatility, coefficients values sharply decrease in the second regime.[15] Note that these coefficients values in second regime underestimate the degree of persistence since past futures trading activities are related to past volatilities and the specification includes past futures trading activities (in the expected futures trading activities variables). Hence, it strengthens our motivations that contemporaneous determinants of volatility must include past volatilities shocks.

Finally, significant and positive coefficients estimates for unexpected volume for both markets in second regime are larger than in the first regime, with suggesting that unexpected volume shock have a positive and larger effect on volatility in the second regime. Similar results are found when examining the magnitude of the significant and negative coefficients estimates for expected open interest for both markets. It implies that an increase in open interest in the second regime lessens the impact of an open interest shock on volatility.

D. Asymmetries in volume and open interest shocks

Table 5 reports results of equation (6) considering effects of unexpected changes in volume and open interest shock on volatility. Dummy variables (Voldum and OpIndum) are defined that equal one for positive unexpected shock and zero for a negative unexpected shock. The product of the dummy variables and unexpected volume and open interest series are also created.

For full period, following Bessembinder and Seguin (1993), we compute the magnitude of the asymmetry and obtain 2.262 for crude oil and 1.460 for heating oil. It means that positive volume shocks have more than twice the effect on price revisions as negative shocks,

[15] Similar results are found in the Tables 5-7.

consistent with findings of Bessembinder and Seguin (1993) and Watanabe (2001). On the other hand, our result is consistent with Bessembinder and Seguin (1993), but not accordant with Watanabe (2001), suggesting that the coefficient estimate for the dummy variable for open interest is insignificant. In sum, significant asymmetries exist for unexpected volume variable for crude oil and for unexpected open interest variable for heating oil.

Table 5 Regressions of estimated daily futures returns standard deviations on trading activity, allowing for asymmetries

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n}\omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n}\eta_i \cdot d_{it} + \sum_{j=1}^{n}\beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m}\mu_k \cdot A_{kt} + \vartheta \cdot Vdum_t \cdot UV_t + \chi \cdot OIdum_t \cdot UOI_t$$

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
Intercept	0.0029**	0.0018*	0.0125**	0.0053**	0.0040**	0.0113**
Monday	0.0037**	0.0043**	0.0014	0.0037**	0.0045**	0.0019
Tuesday	–0.0026**	–0.0020*	–0.0081**	–0.0007	–0.0001	–0.0044*
Wednesday	–0.0005	–0.0009	–0.0034*	0.0019*	0.0016	–0.0003
Thursday	–0.0008	–0.0010	–0.0019	0.0002	0.0004	–0.0016
EV	–0.0027	0.0001	–0.0631	0.0100	0.0108	0.0546
UV	0.1394**	0.1126**	0.2329**	0.0620**	0.0504**	0.2397**
UV×Vdum	0.1759**	0.1780**	0.3333**	0.0285	0.0102	0.1607*
EOI	–0.1372**	–0.1209**	–0.2461**	–0.0303*	–0.0325**	–0.2181**
UOI	–0.5042**	–0.5279**	–0.3692	–0.3622*	–0.2687	–1.8500*
UOI×OIdum	0.5035	0.5378	2.6393*	0.8013**	0.6316*	4.3323**
$\sum\beta$	0.7365**	0.7596**	0.3748**	0.6505**	0.6991**	0.4356**
$\sum\omega$	0.0207	0.0328	–0.1715**	0.1229**	0.1535**	–0.0341
Adj-R^2	0.2469	0.2686	0.2090	0.1777	0.2000	0.1641
DW	1.9860	1.9790	2.0290	1.9870	1.9910	1.9650

Notes: 1.** indicates significant at the 1% level, and * indicates significant at the 5% level.

2. White (1980) standard errors are used.

To confirm the change for positive and negative impact of the unexpected volume (open interest) on volatility, the first and second regimes are compared. Our finding presents that coefficients estimates for unexpected volume (open interest) for both markets in the second regime are larger than in the first regime. It indicates that the marginal impact of negative volume (open interest) shocks on volatility increases in the second regime. Moreover, similar results are obtained when examining the estimated coefficient associated with positive volume (open interest) shocks (which are sum of the unexpected volume (open interest) coefficient plus the cross-product coefficient) in the second regime. It leads to an increase in the marginal effect of a positive volume (open interest) shock in the second regime.

E. Asymmetry in various positive volumes (open interest) shocks percentiles

As volume (open interest) shock increases, it may alter the marginal impact of positive volume (open interest) shock on volatility. To take into account the effect of positive shock quantile levels, Table 6 presents results of equation (7) for the effects of unexpected changes in volume and open interest shock on volatility. Estimates coefficients for the coefficients in equation (7) using the three quantile levels $q \in Q = \{0.01, 0.05, 0.10\}$ are displayed in Table.

During full period, coefficients estimates for unexpected volume for both markets are significant and positive while those for unexpected open interest are significant and negative. When extreme positive volume shocks are explicitly considered in explaining volatilities, coefficients estimates for 0.05 and 0.10 quantile levels of positive volume shocks for both markets are significant and positive while significant negative those for 0.01 qunatile level for crude oil and heating oil. It indicates that more positive shocks lead to an increase in volatility but extreme positive shocks results in a decrease in volatility. Similar findings are presented when considering positive open interest shocks. Coefficients estimates for the 0.05 and 0.10 quantile levels of positive open interest shocks are significantly positive for crude oil and heating oil.

Table 6 Regressions of estimated daily futures returns standard deviations on trading activity, allowing for different asymmetric quantiles

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt} + \sum_{q \in Q} \chi_q^{RUA} \cdot RUA_t^{(1-q)}$$

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
Intercept	0.0046**	0.0037**	0.0151**	0.0056**	0.0042**	0.0140**
Monday	0.0038**	0.0045**	0.0016	0.0035**	0.0044**	0.0016
Tuesday	–0.0027**	–0.0020*	–0.0077**	–0.0011	–0.0004	–0.0043*
Wednesday	–0.0004	–.0008	–0.0027	0.0013	0.0011	–0.0006
Thursday	–0.0007	–0.0008	–0.0017	–0.0002	0.0000	–0.0019
EV	–0.0100	–0.0074	–0.0686	0.0170*	0.0124	0.0614
UV	0.1995**	0.1746**	0.3482**	0.0881**	0.0673**	0.2825**
RUV(q=0.10)	0.2105**	0.1949**	–0.0118	0.1351**	0.1000**	0.2391**
RUV(q=0.05)	0.1079**	0.0921**	0.1327	0.0565**	0.0309	0.1009
RUV(q=0.01)	–0.1198**	–0.0959**	0.3525**	–0.1100**	–0.0691**	0.1034
EOI	–0.0918**	–0.0841**	–0.2273*	–0.0092	–0.0124	–0.2231**
UOI	–0.4391**	–0.4297**	0.2528	–0.3433**	–0.2295	–0.2489
RUOI(q=0.10)	1.6949**	1.5881**	1.3792	1.0126*	1.0547*	0.2215
RUOI(q=0.05)	0.9384**	0.7951*	1.9550	1.2323**	1.0273**	2.1559
RUOI(q=0.01)	0.4320	0.3401	2.8718*	0.0477	–0.0890	3.1682**
$\sum\beta$	0.7181**	0.7399**	0.3841**	0.6691**	0.7114**	0.4481**
$\sum\omega$	0.0154	0.0316	–0.1618*	0.1135**	0.1401**	–0.0278*
Adj-R^2	0.2536	0.2717	0.2056	0.1914	0.2102	0.1611
DW	1.9930	1.9890	2.0260	1.9970	1.9840	1.9570

Notes: 1. ** indicates significant at the 1% level, and * indicates significant at the 5% level.
2. White (1980) standard errors are used.

This table further examines the impact of positive futures trading activity shocks on volatility across two sub-periods. Our finding shows that positive volume shocks for both markets have a larger impact on volatility in the second regime. Specifically, coefficients estimates for the 0.01 quantile level of positive volume shocks for crude oil are significant and positive. Similar results for crude oil and heating are occurred when considering positive open interest shocks. This finding suggests that an increase in open interest results in an increase in volatility in the second regime, indicating that an unexpected open interest increase impacts on the volatility. Our finding fails to support the findings of Bessembinder and Seguin (1993), Fleming and Ostdiek (1999), and Watanabe (2001) that market depth mitigates the volatility.

Briefly, including the left tail does not alter the picture of the asymmetric in the volume-volatility and open interest-volatility for both markets for the full sample and across two sub-samples. Unexpected volumes are positively related to volatility while expected open interest and volatility are negatively associated.

F. Asymmetry in various volumes (open interest) shocks percentiles

We include both tails of unexpected components of futures trading activities in equation (8) to examine an asymmetry in the volume (open interest) -volatility relation. Estimated results with three quantile levels, $q \in Q = \{0.01, 0.05, 0.10\}$, are obtained in Table 7.

We further observe the impact of the left-tails and right-tails of futures trading activities for all markets on volatility during full period and find that lower volume are negative related to the volatility while higher volume and volatility are positively associated. This finding implies that a(n) decrease (increase) in unanticipated volume leads to increase (decrease) volatility. That is, the volume-volatility relation presents v-shaped. It is to note that there is the inverse relation between extremely higher volume and volatility for all markets, suggesting that extreme volumes mitigate the volatility.

On the other hand, our findings present volatility and lower open interest for crude oil contracts are negatively related, suggesting that a decrease in open interest destabilize markets. In addition, it is another to note that, although unexpected open interest for heating oil contract does not impact on volatility, the coefficient estimate for the 0.05 quantile level of positive open interest shock is significant and positive, indicating that an increase in unanticipated open interest aggravate the volatility.

We also examine the stability of the impact of percentages of futures trading activity shocks on volatility across two sub-periods. From Table 7, there are somewhat different relations between volatility and futures trading activity across two regimes. The coefficients estimates for higher volume for both markets turn into positive in the second regime from negative in the first regime. Specifically, the extremely higher volume shocks for crude oil contracts enlarge the volatility. On the other hand, the magnitude of the coefficients estimates for extremely lower volume shocks for crude oil contracts are higher in the second regime then in the first regime, suggesting that a decrease in volume increase the volatility. Then, this table also presents that the coefficient estimate for open interest shock for crude oil contract is significant and positive, indicating that extremely higher open interest leads to an increase in volatility. Finally, extremely lower open interest for both markets and the corresponding volatility are not insignificantly associated. Thus, the impact of volume shocks for markets tends to be stronger in the second regime.

Table 7 Regressions of estimated daily futures returns standard deviations on trading activity, allowing for different symmetric quantiles

$$\hat{\sigma}_t = \delta + \sum_{j=1}^{n} \omega_j \cdot \hat{U}_{t-j} + \sum_{t=4}^{n} \eta_i \cdot d_{it} + \sum_{j=1}^{n} \beta_j \cdot \hat{\sigma}_{t-j} + \sum_{k=1}^{m} \mu_k \cdot A_{kt} + \sum_{q \in Q} \vartheta_q^{LUA} \cdot LUA_t^{(q)} + \sum_{q \in Q} \chi_q^{RUA} \cdot RUA_t^{(1-q)}$$

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
Intercept	0.0042**	0.0032**	0.0153**	0.0061**	0.0048**	0.0135**
Monday	0.0037**	0.0044**	0.0014	0.0035**	0.0042**	0.0015
Tuesday	–0.0028**	–0.0021*	–0.0079**	–0.0018*	–0.0010	–0.0044*
Wednesday	–0.0008	–0.0012	–0.0030*	0.0002	0.0001	–0.0007
Thursday	–0.0010	–0.0011	–0.0018	-0.0010	–0.0006	–0.0020
EV	–0.0028	–0.0015	–0.0588	0.0153*	0.0119	0.0637
UV	0.2908**	0.2602**	0.4121**	0.2154**	0.1773**	0.3363**
LUV(q=0.01)	–0.2186**	–0.1971**	–0.2006*	–0.2110**	–0.1808**	–0.0696
LUV(q=0.05)	–0.1586**	–0.1498**	–0.1239	–0.1464**	–0.1421**	–0.1115
LUV(q=0.10)	–0.0685*	–0.0900**	–0.0693	–0.1100**	–0.0944**	–0.1655

Table 7 Regressions of estimated daily futures returns standard deviations on trading activity, allowing for different symmetric quantiles (continued)

	Crude oil			Heating oil		
Variable	Full	First	Second	Full	First	Second
RUV(q=0.10)	0.1281**	0.1159**	–0.0656	0.0181	0.0005	0.1930**
RUV(q=0.05)	0.0234	0.0124	0.0806	–0.0629**	–0.0744**	0.0546
RUV(q=0.01)	–0.2031**	–0.1743**	0.2989**	–0.2231**	–0.1686**	0.0540
EOI	–0.1120**	–0.1001**	–0.2286*	–0.0236	–0.0264*	–0.2238**
UOI	0.2859	0.2852	–0.0346	–0.1865	–0.0473	0.0525
LUOI(q=0.01)	–0.7273*	–0.6962	0.3094	–0.2601	–0.4509	–0.2594
LUOI(q=0.05)	–1.3982**	–1.2479**	1.1615	0.1528	–0.0025	–0.5811
LUOI(q=0.10)	–0.5235	–0.9845	–0.2099	–0.1066	0.3529	–0.9238
RUOI(q=0.10)	0.7898	0.7208	1.5283	0.4681	0.5623	-0.0438
RUOI(q=0.05)	0.1215	0.0264	2.1726	0.7817*	0.5647	1.8489
RUOI(q=0.01)	–0.2946	–0.3697	3.0905*	–0.2694	–0.4273	2.8582
$\sum\beta$	0.7263**	0.7470**	0.3769**	0.6684**	0.7043**	0.4526**
$\sum\omega$	0.0114	0.0290	-0.1759**	0.1076**	0.1355**	-0.0308
Adj-R^2	0.2645	0.2816	0.2070	0.2056	0.2234	0.1604
DW	1.9890	1.9850	2.0300	1.9870	1.9930	1.9590

Notes: 1. ** indicates significant at the 1% level, and * indicates significant at the 5% level.

2. White (1980) standard errors are used.

IV. Conclusion

This paper examines asymmetric impacts of various percentages of futures trading activities on price volatility for energy futures of crude oil and heating oil at the New York Mercantile Exchange (NYMEX). In addition, to assess where these asymmetries are apparent in energy futures markets, this paper extends the work of Fleming and Ostdiek (1999) to examine asymmetries in volume-volatility and open interest-volatility relations for energy futures, respectively. Next, we use various percentages of futures trading activities to consider asymmetries of this relation. However, due of possible variability in energy futures prices from the early 2000s, our study follows Goldfeld and Quandt (1976) to find the somewhat turbulent time of the 2000s. Therefore, the sample prior to and beginning 2000s are also analyzed separately.

A significant positive relation between unexpected volume and volatility and a significant negative relation between expected open interest and volatility are found to be stronger since 2000s. Specifically, coefficients estimates for unexpected volume for both markets are positive and lager than that for expected volume, demonstrating that unexpected volumes have a positive and larger effect on volatility. We further find that coefficients estimates for higher unexpected volume for both markets turn into positive since 2000s, with negative before 2000s. Specifically, the extremely higher volume shocks for crude oil contracts may enlarge the volatility. On the other hand, the magnitude of the coefficients estimates for extremely lower volume shocks for crude oil contracts are higher since 2000s, suggesting that a decrease in volume sharply increase the volatility. Finally, our finding also presents that extremely higher open interest shock for crude oil contract are significant positive related to the volatility when extremely lower one for both markets and volatility are not insignificantly associated.

To sum, the impact of extremely higher or lower unexpected volume shocks for both markets and extremely higher unexpected open interest shocks for heating oil market on the volatility tends to be stronger since 2000s although the relations of volatility, volume, and open interest for both markets are found to be smaller prior to 2000s. These results are noteworthy because they provide evidence that the relations of volatility, volume, and open interest for energy futures markets may be varying throughout the time.

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能源期貨波動、交易活動和結構轉變*

李瑞琳**

摘 要

本研究以門檻自我回歸模型，針對紐約商品交易所原油和熱燃油能源期貨，探討並驗證能源期貨價格在 2000 年期初是否是結構變動之關鍵點，以釐清價格劇變前後期間，能源期貨交易活動不同大小的百分位數與其價格波動間之不對稱關係。結果驗證 2000 年後樣本期間強列地支持 Bessembinder and Seguin (1993) 結果，意味非預期交易與波動存在正向關係，而預期未平倉合約和波動二者爲負向關係。本文進一步分析非預期期貨交易活動之不同百分位數對波動影響，結果發現 2000 年後，原油和熱燃油能源期貨市場中，極高或極低交易量和極高未平倉合約數分別對波動深具重大影響，尤以熱燃油市場爲最。對照 2000 年前，其影響相對較小。因此，本文結果提供了具有財務意涵的參考價值，即波動、交易量、未平倉合約數間關係具有時變性。

關鍵詞：期貨交易、未平倉合約數、波動、非對稱性、百分位數分析

JEL 分類代碼：Q40, G10, G12, C10

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** 朝陽科技大學財務金融系助理教授，本文聯繫作者。電話：(04)23323000#4490，Email: rllee@cyut.edu.tw。