THE DETERMINANTS OF VOLATILITY ON THE AMERICAN CRUDE OIL FUTURES MARKET

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ABSTRACT. This article focuses on the volatility of crude oil futures prices on the New York Mercantile Exchange. It aims at examining whether this market creates excess volatility, which would not be observed in the absence of such a market. In order to reach this objective, price fluctuations are separated into two components: an information component, that reflects a rational assessment of the information arrival, and an error component, that represents the noise introduced by the trading process. We show that a significant part of the volatility recorded during exchange trading hours is due to mispricing errors. In particular, this phenomenon affects the nearest futures contract.

KEY WORDS: volatility – crude oil – noise trading – information – futures

The volatility of petroleum prices is a major concern for most economic actors. If part of this volatility can be explained by macro-economic factors (such as uncertainties related to China's energy consumption, the nationalization of energy sources, pressures on transportation and refinery capacities...) a frequent explanation emphasizes the attitude of speculators on petroleum futures markets. This explanation recently gained in importance, as a result of the intensified presence of these operators, especially hedge funds. After the burst of the internet bubble in the beginning of the 2000's, numerous investors needed to reallocate their money. At the same time, commodity prices began to rise dramatically and investors began to consider commodities as a new class of assets. They introduced positions on commodity futures contracts in their portfolios of stocks and bonds, in order to improve their return to risk ratio. This resulted in an increase in the transaction volumes on commodity futures markets, especially energy futures markets.

The presence of such operators may be disturbing because their transactions do not always depend on information related to commodities: they could also arise from a sudden change in the stock or bond markets. Thus, if these speculators invest a lot of money, there is a fear that they induce prices moves having no relationship with commodity supply, production, inventory and demand. Moreover, as there is a strong correlation between spot and futures prices, a price's shock on the futures prices of a specific commodity may spread to the physical market. The more pessimistic scenario foretells the contagion to others markets, especially in the case of energy, as a result of tightened cross market linkages due to deregulation.

Do speculators really induce a volatility that would not exist in the absence of a futures market? To answer this question, it is necessary to analyse the different components of volatility. Indeed, the latter comprises both an information component – the arrival of new information has an influence on price levels – and a component that can be interpreted as a noise (Black (1986)). Noise arises from the action of agents who falsely believe that they possess valuable information about what should be the correct price and trade accordingly. Noise traders include investors using technical as opposed to fundamental analysis, trend followers, herders, etc. Although these traders are useful as they serve as liquidity providers for informed investors, they are responsible for excessive volatility due to over-trading, bad timing of their trades, over-reaction to good and bad news, etc.

Through the analysis of the respective part of these two components, this article aims to measure (at least partially) the contribution of speculators to the volatility of crude oil futures prices. Our methodology is inspired by French and Roll (1986). Their seminal work has given rise to numerous researches, first in the stock market (see for example Lauterbach and Monroe (1989), Barclay *et al* (1990), Lockwood and Linn (1990), Stoll and Whaley (1990), Amihud and Mendelson (1991), Chordia *et al* (2006)), then in the currency market (see for example Hertzel *et al* (1990), Harvey *et al* (1991), Cornett *et al* (1993), Ito, Lyons and Melvin (1998)). To the best of our knowledge, only Weiner (2003) applied this framework in the field of commodity markets. His analysis however is restricted to the first Gulf war, and he does not study the contribution of noise to the observed volatility.

It is undoubtedly interesting to focus on the sources of volatility. If it turns out that a significant part of price fluctuations is caused by noise, the efficiency of hedging strategies on derivative markets is likely to be affected. Moreover, from the point of view of regulation, it is important to consider the quality of the services offered by derivative markets, and to ask how effective they are in transferring risk among operators and in providing, through futures prices, informative signals.

This article is organized as follows. Section 1 presents the data. Section 2 is centred on the analysis framework. Section 3 shows that the volatility recorded changes with the trading system (open outcry versus electronic trading) and the analysis period (week-end versus working day). Section 4 is devoted to the quantification of noise trading in volatility. Section 5 concludes.

SECTION 1. DATA

The data used for the study was extracted from Datastream. It correspond to the light, sweet crude oil futures contract of the New York Mercantile Exchange (Nymex). Our sample covers 16.5 years, from the beginning of January 1989 to the end of June 2005.

The Nymex calendar has been reconstructed in order to constitute time series of futures prices that always correspond to fixed monthly maturities¹. We collected daily futures prices related to the opening and settlement prices for all available maturities. Since January 1997, these maturities go as far as seven years. However, due to the lack of reliable data for opening prices on longer expiration dates, we were forced to restrict our study to the first six months. The extraction of data corresponding to transaction volumes shows that, on the period considered, liquidity is concentrated on the six nearest maturities².

SECTION 2. THE ANALYSIS FRAMEWORK

In order to determine whether the transaction process may create an excess volatility (namely pricing errors), we based our methodology on that proposed by French and Roll in 1986. Their framework is quite simple and intuitive. It relies on an empirical observation: on stock markets, prices are usually more volatile during trading hours than non trading hours. Two explanations (which are not mutually exclusive) can be found for this phenomenon. Either it is due to the fact that the presence of a market gives the possibility of immediately reacting to news, and generates volatility due to the incorporation of information into prices. Or it is caused by pricing errors, which occurs preferably during the trading session.

Once the phenomenon of higher volatility during trading hours has been observed, the objective of the analysis is to differentiate between these two possible sources of volatility in order to measure their respective influence: the information component, that reflects a rational assessment of the information arriving during the day, and the error component.

Since 1986, several studies relying on French and Roll have confirmed that the volatility recorded during transaction hours is generally higher than the one which is evidenced during the night or the week-end. They also stated that this higher volatility is at least partially due to noise. In the case of equities and currencies, information processing was also further examined through the use of high frequency data. However, intraday data are not publicly available in the case of the crude oil market.

¹ For example on the 01/21/2003, the futures contract which had, until that date and since the 12/20/2002, a two-month maturity “falls” in the one-month maturity. At the same date, the three-month futures contracts falls in the two-month maturity and the nearest futures contract reaches its delivery date.

² See Appendix 1.

Still, the possibility of distinguishing between opening and settlement prices enables us to have a precise idea of the way prices behave, especially during the open outcry session and during the electronic session.

Among all previously quoted articles, Weiner (2003) is the one which we are closest to. Weiner analyses the impact of the first Gulf war on crude oil futures prices. He compares the returns on these prices when the Nymex is open and when it is closed (overnight³ and over the week-end). The results related to the time periods occurring before and after the Gulf crisis are an addition to previous works on equities and currencies: the volatility recorded during the trading session is higher. On the other hand, during the war, the reverse is true: the daily volatility is lower than the overnight one. According to Weiner, this results from the fact that part of the night in the United States corresponds to a part of the day in the Gulf. He assumes that during the first Gulf crisis, information related to this region of the world constituted the most important source of volatility for crude oil prices.

SECTION 3. VOLATILITY AND TRADING PERIODS

In order to investigate whether the volatility is higher during trading hours, we proceed in three steps. First, we compare daily, overnight and week-end variances. Second, we calculate ratios of daily to overnight variances and of daily to week-end variances. Third, we normalize these indicators in order to take into account the time period used for their calculation.

3.1. Daily, overnight and week-end variances

The first step of the analysis consists in comparing the volatility recorded during the opening hours of the exchange, overnight and over the week-end. For that purpose, we calculate several indicators for each maturity and sub-period of two-years. The first indicator is called daily variance and corresponds to the variance of returns from open to close. It reproduces the behaviour of futures prices during the open outcry session. The second indicator, the overnight variance, corresponds to the variance of returns from close to open. After 1993, it represents the fluctuations recorded when transactions are processed through an electronic system provided by the Nymex. Before that date, it

³ During the period studied by Weyner, there were no electronic overnight transactions.

corresponds to a period without transactions. The third indicator is the week-end variance, namely the variance of returns from Friday close to Monday open. It represents a period without transaction⁴.

Figure 1 summarizes the results obtained from the calculation of these indicators. It depicts the evolution of variances of the one-month futures price over the whole sample period⁵ and shows that daily variances, on the American crude oil futures market, are higher than overnight and week-end variances, except in the case of crises, namely during the first Gulf War and after the Asian crisis, in 1998. This result is in line with the observations made by Weiner (2003) for the period 1990-1991.

[INSÉRT FIGURE 1 HERE]

In order to improve the analysis, the relative importance of these variances can be calculated.

3.2. Variance ratios

A simple indicator of the variances' relative importance can be obtained by calculating the ratios of overnight or week-end variances to daily variances. Moreover, in order to clearly demonstrate the influence of the trading process on volatility, we compute 24-hour variances from the return between two consecutive settlement prices, (we called them 24-hour-variances), and we compare them to week-end variances.

Table 1 reproduces the variance ratios for each maturity on the whole sample period⁶. It also indicates their significance, measured with the Levene test, which takes into account deviations from normality⁷.

[INSERT TABLE 1 HERE]

If hourly variances were the same during trading and non trading periods, the daily variance should be equal to 1/15 of the week-end variance and 1/5 of the overnight variance⁸. Table 1 gives evidence that this is not the case: the ratios are far lower than they should be. For example, the daily to overnight ratios show that volatility is significantly higher during the open outcry sessions than during

⁴ During the week-end, there are a few transaction hours during the night between Sunday and Monday. Outline 1 details the hours of the different trading sessions.

⁵ The results on other maturities are comparable. They are available upon request from the authors.

⁶ For the purpose of presentation, and without any information loss, the results are grouped together into two-year sub-periods. The details are available upon request from the authors.

⁷ Appendix 2 provides details on this test.

⁸ The length of an open outcry trading session is approximately 4 hours, namely 1 sixth of a day (the detailed transaction hours are given in paragraph 3.3). Consequently, the length of overnight sessions is 5/6° of a day and the length of week-end sessions is 15/6°.

the electronic sessions. For the one-month futures prices, the average ratio on the whole period is 2.22 (instead of 1/5).

The daily to overnight ratios are also higher than the daily to week-end ratios, but the differences are not statistically significant. Lastly, for the two nearest futures prices, the 24-hour to week-end ratios are higher than the daily to week-end ratios. This may be due to the fact that overnight trading contributes to the increase of volatility.

3.3. Hourly variances

In order to give more insight into the relative importance of daily, overnight and week-end variances, the indicators above must be normalized, so that the time span used for the computation of the variance is taken into account.

In order to compare daily and week-end variances on an hourly basis we took into account the fact that, as illustrated by Outline 1, until December 2001, the open outcry session on the Nymex began at 9:45 am and ended at 3:10 pm, and that since December 2001, it begins at 10:00 am and ends at 2:30 pm. Thus, the open outcry lasts 5.42 trading hours during the first sub-period, and 4.5 during the second. Likewise, during the first sub-period, the week-end ranges from Friday 3:10 pm to Monday 9:45 am, i.e. 66.58 hours⁹. During the second sub-period, it ranges from Friday 2:30 pm to Sunday 7:00 pm, due to the electronic system. This means that week-end variances do not exactly correspond to a period where there is absolutely no transaction. However, the period with no transaction, before electronic trading begins, represents 80% of the week-end's length.

[INSERT OUTLINE 1 HERE]

If we consider, as a first approximation, that returns are independent, then the variance must be strictly proportional to the length of time used for its calculation. As a result, we can normalize our variances on an hourly basis.

The normalized variances in daily to week-end ratios are depicted on Figure 3. It shows that, on average over the whole period, the hourly variance is much higher over the open outcry session than over the week-end. Moreover, the hourly variance decreases with maturity and consequently,

⁹ As no information is currently available about the opening and closing hours prior to 1997, we considered that those hours are valid from January 1989 to December 1996.

with activity levels in the market. Indeed, the daily variance represents on average 18 times the week-end variance for the six-month maturity, and 23 times for the nearest futures price. We therefore believe that there is a relationship between the intensity of trading and volatility.

The same conclusions are reached with the normalized variance of daily to overnight ratios. More precisely, the daily variance represents on average 6.5 times the week-end variance for the six month maturity, and 8.26 times for the fourth month futures price.

[INSERT FIGURE 3 HERE]

Thus, in the American crude oil market, futures prices are much more volatile during the open outcry session. In concordance with the analysis proposed by French and Roll, two reasons can be invoked in order to explain this phenomenon. It can be due, first of all, to the fact that the rate of information arrival is higher during the opening of the exchange. The presence of a derivative markets, in that case, enables the prices to adjust more quickly to new information, and it introduces, as a consequence, more volatility. The second possible reason is that the process of trading introduces noise into returns (Black, 1986). At this point of the study, it is not possible to determine whether the information arrival or the noise trading dominates. The following section seeks to disentangle these two components of volatility.

SECTION 4. IS THERE NOISE TRADING IN THE CRUDE OIL MARKET ?

Information on noise trading is obtained, first by examining the autocorrelation of daily returns, second by comparing the variances computed on daily returns with variances for a longer holding period, and third by splitting volatility into two parts: an information component and a noise component.

4.1. The autocorrelation of daily returns

Additional information on the noise affecting futures prices can be obtained through the examination of the autocorrelation of daily returns. Indeed, if the crude oil futures market is disturbed by noisy transactions, these noises will create excess volatility. The latter, which does not rely on economical grounds, must disappear (more or less rapidly depending on the efficiency of the market)

thus creating autocorrelations in the returns. In the absence of intra day data, we can identify the part of the noise which lasts more than 24 hours.

Under the trading noise hypothesis, autocorrelations could be either positive or negative.

Positive autocorrelations can be due to over-reaction of traders to new information, with over-reaction persisting more than 24 hours (De Bondt and Thaler, 1985). Consequently, the pricing error occurred during the day should be positively correlated to both information component and pricing errors of the preceding days. Another possible explanation is that the market does not incorporate all information as soon as it is released (Hou et Moscowitz, 2005).

Negative autocorrelations are also consistent with the trading noise hypothesis but naturally, the explanation of this phenomenon differs from the preceding one. In that case, returns are serially correlated because the correction of pricing errors occurs in a period which is longer than one day (Chordia, Roll and Subrahmanyam, 2005). Last but not least, positive and negative autocorrelations may coincide and compensate each others.

Table 2 show the results obtained with close-to-close returns, for the six first contracts, for lags 1 to 10 and for the whole period¹⁰.

[INSERT TABLE 2 HERE]

The results show the presence of significantly negative autocorrelations for all contracts at lags 2 and 6. However let us recall that, as negative and positive autocorrelations may compensate each other, the absence of significant results does not necessarily mean that there is no noise. Table 2 shows, at least, that there is noise trading in the crude oil market and that this noise is mostly due to a correction phenomenon.

In order to quantify the contribution of noise to the total variance, it is possible to compare the variances computed on daily returns (which reflect both information and pricing errors) with variances for a long holding period (which only reflect information).

4.2. Actual versus implied variances

If, as suggested by the presence of negative autocorrelations, a correction phenomenon is present in the crude oil market, the efficiency of the market should, in the long run, result in the noise

¹⁰ The details are available upon request from the authors.

being eliminated (Chordia, Roll and Subrahmanyam (2005)). The comparison of daily variances with variances for a longer holding period aims to demonstrate that valuation errors decrease as the holding period of the futures contracts increases.

If daily returns are totally independent, the variance for a long holding period must be equal to the cumulated daily variances within this period. On the other hand, if daily returns are temporarily affected by trading noise, the longer period variance should be smaller than the cumulated daily variances. Thus, the comparison will enable us to estimate the fraction of the daily variation that is caused by noise trading.

Hereafter, the “actual variance” is the variance of close-to-close returns computed on a specific period of time, whereas the “implied variance” corresponds to the daily variance multiplied by the number of days over the same period.

For each two-year sub-period, the daily variance corresponds to the variance of returns computed on two consecutive trading periods. The weekly variance is obtained through one week rolling windows. Each window begins at the Tuesday close and ends at the next Tuesday close. The same method is retained for the computation of two-, three- and four-week variances¹¹; however, the length of the rolling windows is fixed at one week. Considering the fact that one week consists of 5 trading days and the year 254 days, the one-week implied variance corresponds to the daily variance of the sub-period multiplied by (5/254), the two-week is obtained through a multiplication by (10/254), etc.

Table 3 reproduces the average actual-to-implied variance ratios that were obtained on the study period¹².

[INSERT TABLE 3 HERE]

The results of Table 3 indicate that a significant fraction of the daily variance is caused by pricing errors. Indeed, the actual-to-implied variance ratio is inferior to one, except for the one-week ratios. This exception is however in concordance with the presence of significant autocorrelations at

¹¹ On the American crude oil market, the maturity of a futures contract changes every month (see footnote no. 2). Thus, one month is the maximal holding period retained in the study.

¹² The details are available upon request from the authors. They do not differ significantly from the summary shown in Table 3, except for the ratios corresponding to the first Gulf War, which are lower for all maturities. This result can be explained by an increase in the noise in the daily variance, linked to the high level of activity recorded over that period.

lag 6 in Table 2. These autocorrelations reflect the persistence of pricing errors on more than one week. Furthermore, the ratios diminish when the length of the holding period increases. This supports the assumption that pricing errors do not affect futures prices in the long run.

For example, the average one-month actual-to-implied variance ratio for the nearby futures contract is 0.712 over the period. We can infer that 28.8% of the daily variance of this futures contract is eliminated in the long run.

4.3. Does noise trading really matter?

Once the presence of noisy trading has been established, it is still necessary to determine to what extent noise is responsible of the high volatility recorded during trading hours.

To obtain that result, two kinds of variance ratios are used. The first are the variance ratios in Table 1, which reflect the relative importance of daily, overnight and week-end variances. These ratios are far higher than they should be if the variances of hourly returns were constant irrespective of time period. Are these high variance ratios caused by an increase in the arrival of information when the exchange is open or / and by a rise in the pricing errors due to trading? This can be answered by using both these variance ratios and the one-month actual-to-implied variance ratios presented in Table 3.

Let us consider that the one-month implied variance represents the part of daily variance which is solely due to information. In this context, it is possible to use the one-month actual-to-implied variance ratios in order to estimate new variance ratios. These new estimated ratios correspond to those presented in Table 1, except for the fact that they are corrected for noise. These estimates correspond to the maximum values that the ratios in Table 1 would reach if the noise was as strong during trading hours as over the week-end¹³. The comparison between the former and estimated ratios gives a value for the upper bound of the noise recorded during trading hours.

The estimated ratios are obtained using the following method. Let us consider that the daily return (R_t) is made up of two components: a rational information component (X_t) and a mispricing component (Z_t):

$$R_t = X_t + Z_t$$

¹³ Once again, we consider that there are no transactions over the week-end.

Then, let us assume that noise recorded during trading hours is as strong as the noise recorded over the week-end. This assumption magnifies the noise element in daily returns, because the quantity of noise taken into account corresponds to the noise that would otherwise be recorded over two trading days. Based on this assumption, the trading and weekend returns (R_{qt} and R_{wt}) can be presented as follows:

$$R_{qt} = X_{qt} + Z_t$$

$$R_{wt} = X_{wt} + Z_t$$

Based on the ratios in Table 1, the variance of close-to-close returns equals 2.65 times the week-end variance, for the nearby futures contract, and for the whole period:

$$Var(X_{qt} + Z_t) = 2.65 Var(X_{wt} + Z_t)$$

or, more generally:

$$Var(X_{qt} + Z_t) = a Var(X_{wt} + Z_t)$$

where a represents the variance ratio close-to-close/week-end.

For the same futures contract and the same period, the one-month actual-to-implied variance ratio is 0.712. Let us assume that this ratio can be applied to the week-end variance (which again exaggerates the noise element in the close-to-close variance):

$$Var(X_{wt}) = 0.712 Var(X_{wt} + Z_t).$$

or, more generally :

$$Var(X_{wt}) = b Var(X_{wt} + Z_t).$$

where b represents the actual-to-implied variance ratio.

On the assumption that the information and mispricing components are independent, these equations can be combined to eliminate the pricing error variances:

$$Var(X_{qt}) = 3.32 Var(X_{wt})$$

or, more generally :

$$Var(X_{qt}) = \frac{ab}{1 - a + ab} Var(X_{wt})$$

Table 4 shows the results obtained using this methodology, for each futures contract. The comparison between the former and estimated ratios shows the maximum contribution of noise to

daily variance. This contribution changes noticeably in step with the futures contracts. Noise has a greater impact on the nearby contract: the maximum contribution of noise to the variance of this contract reaches 25.2%, which is rather high. As far as the other contracts are concerned, noise seems to rise along the maturity curve. This increase can be explained by the decline in the trading volumes. However, this explanation can not be retained for the one-month contract, which is the most liquid one. Thus, on this maturity the presence of a derivative market creates excess volatility. This specific behaviour of the one-month contract may be due to the roll-over of the positions when the contract reaches maturity.

[INSERT TABLE 4 HERE]

SECTION 5. CONCLUSION

Several results can be obtained from this study of the crude oil American market. First, we observe that daily variances are higher than overnight variances, which in turn are higher than weekend variances. This hierarchy remains true for the whole sample, except for two specific periods, namely the first Gulf war and the Asian crisis. Two reasons can be called upon in order to explain this rise in the volatility during trading hours: first, even if the crude oil market is world-wide, information arrives primarily during trading hours. Second, excess volatility (ie mispricing errors) is caused by trading.

In order to obtain more information on volatility and on noise trading, we studied the autocorrelations of daily returns. Indeed, the presence of noise can create serial correlations in the rate of returns. As a matter of fact, we identified significant, mainly negative autocorrelations. This is compatible with the presence of a correction effect. The latter is corroborated by the results obtained from comparing daily variances with variances on a longer holding period. This comparison also shows that a large part of the daily volatility is eliminated in the long run (one month). Lastly, we estimate the maximum impact noise can have in the daily variance, and we show that the nearby contract is particularly impacted by pricing errors, since noise can represent up to 25% of its total variance.

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**Figure 1. Daily, overnight and week-end variances, nearby futures contract, Light Sweet Crude Oil,
1989-2005**

Figure 2. Normalized variance ratios, Daily / Week-end, Light Sweet Crude Oil, 1989-2005

Outline 1. Trading hours, New York Mercantile Exchange

This outline depicts the time line of the trading sessions (open outcry and electronic session) for the *Light Sweet Crude Oil* future contract traded on the New York Mercantile Exchange since January 1997, along with the periods of market closure.

- From January 1997 to 11/06/2001

- Since 12/06/2001

○ Weekdays

○ Weekends

Table 1. Variance ratios

This table reports the value of the Daily/overnight, Daily/week-end and Close-to-close/week-end ratios for the eight two-year sub-periods over 1989-2005. The null hypothesis that the value of a given ratio is equal to one is tested using Levene (1960) statistic. Asterisks ***, **, *, denote the rejection of the hypothesis at the 1%, 5% and 10% levels, respectively, in a bilateral test.

Daily / overnight ratio						
	1 month	2 months	3 months	4 months	5 months	6 months
1989-90	1.460 ***	1.356 ***	1.439 ***	1.620 ***	1.699 ***	1.782 ***
1991-92	0.939 ***	0.655 ***	1.889 ***	1.599 ***	0.522 ***	0.607 ***
1993-94	3.673 ***	3.478 ***	3.383 ***	4.784 ***	4.416 ***	4.244 ***
1995-96	2.152 ***	2.586 ***	2.863 ***	2.922 ***	3.119 ***	1.026 ***
1997-98	4.092 ***	2.825 ***	2.947 ***	2.986 ***	3.262 ***	2.472 ***
1999-00	1.659 ***	2.061 ***	2.060 ***	2.146 ***	1.750 ***	1.960 ***
2001-02	1.692 ***	1.916 ***	1.926 ***	1.848 ***	2.013 ***	1.455 ***
2003-05	2.102 ***	2.211 ***	2.316 ***	2.262 ***	2.212 ***	2.196 ***
Average	2.221	2.136	2.353	2.521	2.374	1.968

Daily / week-end Ratio						
	1 month	2 months	3 months	4 months	5 months	6 months
1989-90	0.830	0.592	0.567	0.551	0.577	0.666
1991-92	0.798 **	0.686 *	1.445 *	1.507 **	0.851 ***	0.797 **
1993-94	1.868 ***	1.979 ***	1.777 ***	1.999 ***	2.104 ***	1.912 **
1995-96	4.572 ***	3.176 ***	3.050 ***	2.688 ***	2.557 ***	2.765 ***
1997-98	0.826 **	0.781 **	0.963 **	1.005 ***	0.903 *	0.706
1999-00	2.484 ***	2.290 ***	2.284 ***	2.299 ***	1.889 ***	1.383 *
2001-02	1.416 *	1.309	1.273	1.292	1.119	1.229
2003-05	1.950 ***	2.396 ***	2.322 ***	2.162 ***	2.157 ***	1.779 **
Average	1.843	1.651	1.710	1.688	1.520	1.405

Close-to-close / week-end Ratio						
	1 month	2 months	3 months	4 months	5 months	6 months
1989-90	1.311 **	0.841	0.779	0.749	0.736	0.810
1991-92	2.131 **	2.053 *	2.777 **	2.936 **	2.095 ***	1.767 **
1993-94	1.851 ***	1.856 ***	1.517 ***	1.808 ***	1.950 ***	1.805 ***
1995-96	5.842 ***	3.718 ***	3.465 ***	3.002 ***	2.797 ***	4.678 ***
1997-98	0.955 ***	1.003 **	1.232 ***	1.178 ***	1.040 **	0.935 **
1999-00	4.202 ***	3.839 ***	3.729 ***	3.295 ***	2.855 ***	2.095 ***
2001-02	2.054 ***	1.752 ***	1.772 ***	1.813 ***	1.503 **	1.782 ***
2003-05	2.852 ***	3.381 ***	3.198 ***	3.057 ***	3.146 ***	2.743 ***
Average	2.650	2.305	2.309	2.230	2.015	2.077

Table 2. Autocorrelations

Autocorrelations are given in percent. The autocorrelations at the various lags are first computed for each contract and each of the eight two-year sub-periods over January 1989 – June 2005, after which the per-period autocorrelations are averaged. The t-stat and the p-value are computed from the distribution of the autocorrelations on the eight sub-periods.

		1 month	2 months	3 months	4 months	5 months	6 months
Lag 1	coeff	1.183	1.752	2.066	0.272	-1.420	-4.322
	t-stat	0.85	1.19	1.47	0.18	0.83	2.06
	p-value	0.43	0.27	0.18	0.87	0.43	0.08
Lag 2	coeff	-6.831	-4.248	-4.808	-4.533	-4.515	-4.461
	t-stat	2.46	1.80	1.79	1.95	2.04	1.96
	p-value	0.04	0.12	0.12	0.09	0.08	0.09
Lag 3	coeff	-5.385	-4.820	-4.292	-4.503	-4.553	-4.815
	t-stat	1.76	1.47	1.46	1.59	1.61	1.55
	p-value	0.12	0.19	0.19	0.16	0.15	0.16
Lag 4	coeff	2.122	0.989	1.290	1.427	1.474	1.771
	t-stat	1.27	0.69	1.02	1.35	1.76	2.26
	p-value	0.25	0.51	0.34	0.22	0.12	0.06
Lag 5	coeff	-2.293	-1.846	-1.924	-1.649	-1.860	-1.069
	t-stat	1.24	0.91	0.94	0.78	0.73	0.41
	p-value	0.26	0.39	0.38	0.46	0.49	0.69
Lag 6	coeff	-4.095	-3.998	-4.060	-3.857	-3.196	-3.418
	t-stat	3.14	2.98	3.47	3.17	2.35	2.97
	p-value	0.02	0.02	0.01	0.02	0.05	0.02
Lag 7	coeff	-1.505	0.047	-0.740	-0.273	-0.673	-0.192
	t-stat	1.20	0.04	0.61	0.26	0.81	0.22
	p-value	0.27	0.97	0.56	0.80	0.44	0.83
Lag 8	coeff	-3.001	-3.136	-2.689	-3.478	-3.622	-3.092
	t-stat	1.15	1.21	1.25	1.69	1.74	1.47
	p-value	0.29	0.27	0.25	0.14	0.13	0.19
Lag 9	coeff	-0.510	-1.104	-1.201	-0.760	-0.970	-1.653
	t-stat	0.27	0.66	0.70	0.43	0.57	1.05
	p-value	0.80	0.53	0.50	0.68	0.58	0.33
Lag 10	coeff	0.804	2.165	2.835	2.570	2.522	2.498
	t-stat	0.32	0.81	1.13	1.13	1.12	1.18
	p-value	0.76	0.44	0.29	0.30	0.30	0.28

Table 3. Actual-to-implied variance ratios

This table reports the value of the actual-to-implied variance ratios for 1 month to 6 month maturity contracts on Light Sweet Crude Oil, traded on the New York Mercantile Exchange from 1989 to 2005. The ratios are computed for holding periods ranging from 1 week to 1 month. The actual variance is computed from close-to-close returns on a given time period (1, 2, 3 weeks and 1 month), and the implied variance is computed as the product of the daily variance times the number of days on the corresponding holding period.

	1 month	2 months	3 months	4 months	5 months	6 months
1 week	1.046	1.075	1.073	1.056	1.022	0.973
T-stat	0.52	0.68	0.70	0.57	0.23	0.30
p-value	0.62	0.52	0.50	0.59	0.82	0.77
2 weeks	0.847	0.910	0.908	0.892	0.857	0.811
T-stat	1.98	0.93	1.12	1.53	2.41	3.24
p-value	0.09	0.39	0.30	0.17	0.05	0.01
3 weeks	0.750	0.836	0.836	0.824	0.790	0.746
T-stat	4.30	1.95	2.42	2.99	4.50	4.87
p-value	0.00	0.09	0.05	0.02	0.00	0.00
1 month	0.712	0.813	0.811	0.798	0.762	0.714
T-stat	4.14	1.91	2.33	2.81	4.05	4.51
p-value	0.00	0.10	0.05	0.03	0.00	0.00

Table 4. Noise-adjusted variance ratios

This table reports the value of variance ratios for 1 month to 6 month maturity contracts on Light Sweet Crude Oil, traded on the New York Mercantile Exchange from 1989 to 2005. Crude ratios are computed as the average of the per-period close-to-close / week-end ratios reported in Table 1. Adjusted ratios correspond to the estimate of the theoretical value of the ratios under the assumption that the amount of noise during the daily trading session is as large as the amount of noise over the week-end. Variation reports the upper-bound of the variance induced by noise trading.

	1 month	2 months	3 months	4 months	5 months	6 months
Crude ratios	2.65	2.31	2.31	2.23	2.02	2.08
Adjusted ratios	3.32	2.60	2.61	2.54	2.33	2.51
Variation	25.20%	13.00%	13.20%	13.98%	15.72%	20.80%

Appendix 1. Proportion of short-term contracts in the total trading volume

This appendix reports the proportion of short-term *light sweet crude oil* contracts in the total trading volume on the New York Mercantile Exchange from 1989 to 2005, under various specifications for the contracts of interest, namely:

- 1-month maturity contracts,
- 1 to 3-month maturity contracts,
- 1 to 6-month maturity contracts.

Those proportions are reported in percent for each of the 2-year sub-periods. The total trading volume is computed using all contracts available for the various maturities. Since January 1997, 7-year contracts are available.

	1 month	1 to 3 months	1 to 6 months
1989-90	38.02	82.20	94.34
1991-92	38.02	85.07	94.33
1993-94	38.00	83.77	94.31
1995-96	38.01	81.51	94.30
1997-98	38.02	82.57	94.29
1999-00	38.04	83.92	94.28
2001-02	38.03	84.24	94.27
2003-05	38.05	84.51	94.25

Appendix 2. Levene (1960) robust test for the equality of variances

The Levene (1960) statistic aims at testing the equality of variances among k samples. As opposed to Fisher or Bartlett's test, the Levene test is robust in presence of deviations with respect to the assumption of normality for returns. The Levene test aims at differentiating between the following hypotheses:

$$H_0 : \sigma_1 = \sigma_2 = \dots = \sigma_k, \text{ and}$$

$$H_a : \sigma_i \neq \sigma_j \text{ for at least one pair } (i,j)$$

Let us denote Y a random variable on a sample of size n divided into k sub-samples. Denoting n_i the number of observations for the i^{th} sub-sample, the Levene statistic is given by:

$$W = \frac{(n-k) \sum_{i=1}^k n_i (\bar{Z}_i - \bar{Z}_{i,j})^2}{(k-1) \sum_{i=1}^k \sum_{j=1}^{n_i} (Z_{i,j} - \bar{Z}_{i,j})^2}$$

where:

$$- Z_{i,j} = \left| Y_{i,j} - \tilde{Y}_i \right|$$

- $\tilde{Y}_i$, denotes the median for the i^{th} sub-sample,

- $\bar{Z}_i$, denotes the average of $Z_{i,j}$ within sub-sample i ,

- $\bar{Z}_{i,j}$, denotes the grand-average of $Z_{i,j}$.

The Levene statistic is distributed Fischer $F(k-1, n-k)$.