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THE EFFECT OF MATURITY, TRADING VOLUME, AND OPEN INTEREST ON CRUDE OIL FUTURES PRICE RANGE-BASED VOLATILITY

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Abstract

The determinants of the volatility of crude oil futures prices are examined using an intra-day range-based measure of volatility. A contract-by-contract analysis reveals trading volume and open interest to be significant determinants of volatility; dominating the Samuelson maturity effect. The results support earlier findings of a positive and significant role for trading volume, and they also show the importance of open interest in determining volatility, exerting a significant negative effect. A full-period time series analysis also demonstrates the significant role played by open interest in the determination of futures price volatility and further confirms the importance of trading volume.

JEL Classifications: G10, G12, G13

Keywords: Volatility, futures, trading volume, open interest, maturity

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1. Introduction

The objective of our research is to analyze the relation between the volatility of futures prices and the maturity of contracts, trading volume, and open interest. The concept of open interest is introduced to evaluate the influence of this additional measure of market activity in explaining volatility. We find that, whether we examine the relation on a contract-by-contract basis or via time series analysis over an eleven year period, open interest does contribute significantly to the explanation of futures volatility for the New York Mercantile Exchange (NYMEX) crude oil contract.

The introduction of open interest as an additional explanatory variable is motivated by the fact that open interest and its change differ significantly from trading volume, which is why we expect it to provide additional explanatory power. Open interest is defined as the number of contracts existing in a futures market that have not yet been closed out. It is reported as the number of outstanding contracts at the end of a trading day. Open interest increases from zero when a contract is first listed for trading, falling back to zero on the maturity date of the underlying contract when trading ceases. It typically reaches a maximum about one month before maturity. We expect open interest to provide additional information because the relation between open interest and trading volume is quite complex, which means that trading volume alone cannot be expected to reveal effectively this additional information.

Futures markets differ from equity markets (or cash markets in general) in many respects. One specific element of difference has to do with open interest, as there is no directly comparable measure in equity markets. In the latter, there are a number of outstanding shares that may be traded, in which case the observed trading volume captures the number of the shares traded by market participants. Of specific note is the fact that trading volume does not affect the number of outstanding shares, which is determined by a policy decision of the corporate board, thus increasing or decreasing infrequently.

In the futures markets, however, there is no set number of outstanding contracts to be traded. Contracts come into existence simply through the interaction of two parties who are interested in buying and selling a contract. There is no direct, monotonic link between trading volume and open interest, which are effectively flow and stock measures of activity, respectively. However, it is the exception, rather than the rule, to find that a change in open interest between two trading days is equal to the trading volume that occurs during the day. For any given trading volume, the open interest for a contract may rise, fall, or remain unchanged.

Consider first a case where open interest rises. When two new traders (not already holding positions in the market) come to the market, one buying (going long) and the other selling (going short) a single contract, their activity will result in trading volume of one contract, and it also leads to a one-contract increase in open interest. Consider now a case where open interest is unchanged. When a new trader comes to the market and goes long, trading volume will be one contract but this will cause no change in open interest if the contract purchased is owned by a trader who decided to close an existing position. In this case, the activity resembles that observed in equity markets. Finally, consider a case when open interest falls. When two traders already in the market (one long and the other short) close their respective positions against one another, trading volume will be one contract, but open interest will decline by one contract. In this case, the long trader closes the position by going short, whereas the short trader closes the position by going long. In each case, a trading volume of one is observed regardless of the effect on open interest. Therefore, an observation of a trade cannot differentiate among increasing, decreasing, or unchanged open interest. It is therefore necessary to include observations on open interest directly to be able to determine whether or not this trading activity variable influences the volatility of futures prices separately from trading volume.

The role of open interest in determining the volatility of futures prices is of interest to hedgers and investors. The expectation is that open interest is negatively related to volatility, as the availability of more contracts represents increased market depth, implying greater liquidity. This effect tends to offset the expected positive influence of trading volume.

2. Literature review

The literature contains numerous examples of papers attempting to identify the important variables that influence the volatility of futures prices. Viewed as the seminal paper in this strand of research, Samuelson (1965) demonstrated that the volatility of futures contracts should increase as the maturity date is approached. The logic behind this conclusion is that the market is more sensitive to news regarding near-maturity contracts than more-distant contracts, which is indicated by greater volatility for the near-maturity contract. An alternative way to think about this effect is to note that news is more relevant to near-term market concerns rather than to those distant in time. An econometric specification of this relation should include a measure of volatility as the dependent variable and a measure of contract maturity as the explanatory variable. Typically, the maturity variable is a decreasing counter/index, whereas the expected outcome is to find the estimated coefficient to be significantly negative.

The hypothesis of the maturity effect in futures prices has been tested extensively using a variety of futures contracts and model specifications including a range of additional explanatory variables. The results of these many studies are mixed. For example, the seasonal effect is more important than the maturity effect for agricultural commodities (for example, Anderson, 1985; Kenyon et al., 1987). It has also been found that the maturity effect plays a significant role in determining the volatility of futures prices of commodities that are characterized by seasonal supply or demand but not when the cost-of-carry model of futures prices works well, such as financial futures (for example, Galloway and Kolb 1996; Moosa and Bollen 2001).

Serletis (1992) estimated the effect of maturity and trading volume on the price volatility of NYMEX energy futures contracts over the period of January 1987 to July 1990. His model augments the Samuelson-type volatility-maturity model with observations on trading volume. The contracts he examined included crude oil, heating oil and unleaded gasoline (43 contracts for each). He used all observations for a contract from the first trading day to maturity. The measure of volatility he used, which is based on the work of Parkinson (1980) and Garman and Klass (1980), is calculated from the high and low prices observed for each trading day. He conducted the analysis on a contract-by-contract basis. For crude oil he found that once trading volume is added to the specification, the number of contracts that exhibit significantly negative coefficients on maturity falls to about 30 percent (13 out of 43) from 65 percent (28 out of 43) when maturity is specified alone. Similar results were found for the other two contracts. One concern about the work of Serletis is the inclusion of data extending back to the initial trading days of a contract when there is often little or no trading activity. The market is not focused on these contracts because they are by definition far from maturity, and their economic effect is distant from the current physical market activity.

Herbert (1995) studied the relation between volatility and maturity and trading volume for the natural gas futures traded on the NYMEX over the period from June 1990 to May 1994. He employed the same high-low price measure of volatility as Serletis (1992), but he used the observations for near-month contracts only. The decision to limit observations was explained by noting concerns about the lack of trading activity during the early months of trading in a contract. However, this decision also introduces limitations, since it reduces the average number of observations per contract to around twenty. The results reported by Herbert fail to support Samuelson’s finding that volatility should increase as maturity is approached. For the natural gas contracts, even when maturity is specified alone, the number of significant negative coefficients is only 13 out of 47, or 28 percent. Once trading volume is included in the specification, this falls to 3 out of 47, or 6 percent. These results led Herbert to conclude that trading volume dominates maturity in explaining futures returns volatility.

Bessembinder and Seguin (1993) employ a different modeling approach. They use a measure of volatility based on daily closing prices and time series methods rather than examining single contracts. As such, there is no role for a maturity variable, but in addition to trading volume they introduce open interest as a measure of trading activity, which is meant to capture market depth.[1] Their analysis of near-month contract price volatility employs observations for both trading volume and open interest that represent aggregations over all traded contracts, no matter how distant the maturity is. Their results indicate that trading volume has a significant positive effect on volatility, whereas open interest has a significant negative effect.

This paper extends this research. We follow Serletis (1992) and Herbert (1995) by using the high-low price measure of volatility, and, following Bessembinder and Seguin (1993), we bring open interest into the analysis. We examine the relations both on a contract-by-contract basis and in a time series framework. We address the stated data issues for both approaches. In our time series analysis we employ observations on trading volume and open interest for the specific contract of interest rather than aggregates for all traded contracts. We also take an intermediate position between Serletis (1992) and Herbert (1995) by employing two months of observations for each contract rather than all (Serletis) or just one month (Herbert). This adds useful observations without reaching too far into the relatively lightly traded past of a contract.

3. Model specification and methodology

In this section we discuss the model structure and model selection methodology employed to evaluate the role of each of the three explanatory variables: maturity, trading volume and open interest. We utilize two approaches, one employing data on a contract-by-contract basis and the other employing a time series framework for the entire period. The former calls for analyzing the data associated with individual contracts and determining what is the most meaningful set of data for a

[1] They examine eight futures contracts, including currencies, metals, agricultural commodities, and financials, but they did not include any energy futures contracts.

contract, whereas the latter requires "splicing" together the data series over the entire period.

The models and estimation methods must also differ as a result of these different approaches. For example, there is no meaningful role to be played by maturity when we use the spliced time series data. For the contract-by-contract analysis, the series length seriously limits our ability to assess lag structures for the variables, a limitation that does not hold for the full-period time series analysis.

We begin with a contract-by-contract analysis. Our basic specification is as follows:

$$s_t = \beta_0 + \beta_1 m_t + \beta_2 v_t + \beta_3 o_t + \varepsilon_t \tag{1}$$

where s is the measure of volatility, calculated as $(\ln(H) - \ln(L))^2 / (4 \ln 2)$, where H represents the high price recorded for the day's trading and L is the low price for the day. m is the maturity variable, which is a simple decreasing counter; v is trading volume; o is open interest; and ε is the regression residual term. For the purpose of scaling the variables, s is multiplied by a factor of 10,000 and m is measured in units of 10 days, whereas v and o are measured in units of 10,000 contracts.

We follow Herbert (1995) by not transforming these variables into logarithms but, unlike Herbert, we base this decision on non-nested tests for alternative linear specifications. The non-nested models are M1, in which the explanatory variables are in levels and M2, in which the explanatory variables are in log-levels. The models M1 and M2 are said to be non-nested if the regressors of either of them cannot be expressed as an exact linear combination of the regressors of the other. Six model selection tests are used.[2] The tests are run both ways by testing M1 versus M2 and M2 versus M1. When M1 is tested versus M2, the null hypothesis is that M1 is a better model (in terms of specification) than M2. A significant test statistic rejects the null, indicating that M1 is not a better model

[2] *N* is the Cox test derived in Pesaran (1974); *NT* is the adjusted Cox test derived in Godfrey and Pesaran (1983); *W* is the Wald-type test proposed by Godfrey and Pesaran (1983); *J* is the Davidson and MacKinnon (1981) test; *JA* is the Fisher-McAleer (1981) test; and *EN* is the encompassing test proposed, *inter alia*, by Mizon and Richard (1986). All of the test statistics have *t* distribution, except for the encompassing test, which is *F* distributed.

than M2. The reverse holds when M2 is tested against M1. If we obtain significant test statistics both ways, the two models are misspecified. If we get insignificant test statistics by testing M1 versus M2 and significant statistics by testing M2 versus M1, this means that M1 is preferred to M2. The econometrics of non-nested model selection tests can be found in Pesaran and Pesaran (1997).

We accept the results of earlier work that include both maturity and trading volume variables, and we then systematically examine alternative specifications to find out whether or not open interest should be included in the equation to explain volatility. This allows us to make direct comparisons of our results with those of Serletis (1992) and Herbert (1995), while extending the literature by evaluating the role of open interest as an explanatory variable. We employ non-nested tests for alternative specifications, as well as tests for both the deletion and addition of variables to evaluate the inclusion of open interest in the specification. These tests are applied to open interest such that significant test statistics imply that open interest is an important variable.[3]

Following our examination of the contract-by-contract data, we conclude that maturity may be dropped from the specification. Out of 131 contracts, we find that only 5 percent (7 out of 131) of the estimated coefficients on maturity are significant and negative. We turn next to the full-period time series analysis that does not include a maturity variable.

The time series specification is as follows:

$$s_t = \beta_0 + \sum_{l=1}^{n} \beta_{1l} s_{t-l} + \sum_{i=0}^{p} \beta_{2i} v_{t-i} + \sum_{j=0}^{q} \beta_{3j} o_{t-j} + \varepsilon_t \tag{2}$$

This model is estimated over the entire eleven year period, employing the autoregressive distributive lag methodology. The ARDL(*n*,*p*,*q*) specification selection criterion used is the Schwarz Bayesian Criterion (SBC), which produces

[3] Three test statistics are used for this purpose: LM and LR statistics (both with a χ^2 distribution) and an F-statistic. The null hypothesis in all cases is that the coefficient on the deleted or added variable is zero. In the case of the variable deletion test, we start from a model that contains all three explanatory variables and impose the restriction that the coefficient on open interest is zero. In the case of the variable addition test, we start from a model that has maturity and volume as the explanatory variables, then measure the effect of adding open interest as an explanatory variable.

an optimal selection of ARDL(5,5,0). The Akaike Information Criterion (AIC) selected model tends to contain more lags for each variable, producing an ARDL(6,5,7) model.[4] Qualitatively, the results are relatively robust to the model selection criteria employed. The variables are defined the same as for the contract-by-contract estimation.

4. Data Collection and Processing

The crude oil futures contract series are sourced directly from the NYMEX. The sample of daily data covers the period January 1995 through December 2005. For the contract-by-contract analysis, we use 131 contracts, and for the full-period time series analysis we have 2,739 daily observations. These data series cover the daily high and low prices, trading volume, and open interest. The high and low prices are used to construct a volatility measure, as defined earlier.

Each estimation operation requires special handling of the data. As noted above, Serletis (1992) used all observations for a contract beginning with its listing, whereas Herbert (1995) used only the first month. In our contract-by-contract analysis, we employ the last two months of the series observations to take advantage of as much meaningful data as possible. With the objective of having observations to be representative of the focus of market activity, our choice falls on two months as the length of the period used to analyze the relation between the high, low and settlement prices for the individual contracts.

The daily settlement price is determined by the Exchange Settlement Committee for all but a very few near-maturity contracts. For thinly-traded contracts, especially those for far distant maturity, it is not unusual to observe a settlement price that is outside the range for the daily high and low for that contract. This results from the judgment of the Committee as to the overall market sentiment, which is motivated by the desire to maintain continuity between different maturities even in the face of limited (or no) trading in some distant

[4] Given the number of observations and variables, *Microfit 4.0* limited the maximum number of lags that could be estimated to seven. All possible models are estimated, and setting the maximum lag length to seven implies that 512 models are estimated; $(m+1)^{k+1}$, where m=7 is the specified maximum lags and k=2 is number of explanatory variables.

maturity contracts. We determined that for nearly all of the 131 contracts, the settlement price was observed to fall within the high-low price range throughout the last two months of trading. This implies that the volatility measure constructed from the daily high and low prices should provide a good representation of volatility. Reflecting on Serletis (1992), this suggests that much of his constructed volatility observations, based on the same daily high and low methodology, were not representative of the market's actual assessment of the volatility of the contracts, since it would be revealed that settlement prices for most of the contracts maturing beyond two months would have fallen outside of the high-low range. On the other hand, Herbert's (1995) use of only near-month observations ignores information that is representative of the volatility associated with market activity. Our choice of two months of observations typically results in more than 40 observations, doubling the number of observations used by Herbert (1995).

The full-period time series analysis requires the construction of a spliced time series for the eleven-year period. Since all futures contracts eventually mature and cease to trade, the typical approach is to splice the near-month prices for consecutive contracts. We employ a somewhat different splicing methodology, which employs prices and associated trading activity that are representative of the focus of the market. As a contract approaches maturity, the market shifts its attention away from the near-month contract to the next-to-near-month contract before the near-month contract reaches its last trading day. Our methodology avoids using observations near the maturity date of the contracts, which represent waning, and frequently unstable, market interest.

We established a two-criterion test to determine when we should shift from the near-month contract observations to the next-to-near month contract. When both the daily trading volume and open interest for the next-to-near month contract exceed those for the near-month contract, we take this as evidence that the market's attention has shifted away from the near-month contract. At this point we shift the series to the next-to-near month contract.[5] This methodology also has the effect of smoothing the series. For example, if we splice the series on

[5] Through extensive testing, we have determined that once both conditions are met, the near-month contract never again regains the focus of trading activity.

the last trading day, the shift from the closing near-month contract to the new near-month contract will see observations on open interest leap from zero (or very close to zero) to substantially large open interest. This leap is an artifact of the life-cycle of futures contracts that does not really carry meaningful market information.

Finally, our approach differs from that of Bessembinder and Seguin (1993) by considering the trading volume and open interest matching the contract prices that are the basis for our volatility measure. Rather than implying that there is some unidentified role to be played by total market trading activity in determining the near-month contract price volatility, we estimate the relation between a contract's price volatility and its own trading activity.

5. Results

We first select our model specification for the contract-by-contract analysis. We test model specification in a stepwise process. In contrast to Herbert (1995), who arbitrarily chose to use explanatory variables in levels, we employ non-nested tests of the alternative specifications with explanatory variables in levels versus log-levels. We include all three variables (maturity, trading volume, and open interest) in these tests, and we then follow on with additional non-tested tests and variable deletion/addition tests specifically for the inclusion of open interest in our model specification. This is then followed by the full-period time series results.

5.1. *Contract-by-contract analysis*

Table 1 reports the results of non-nested model selection tests for the alternative levels versus the log-levels models (M1 and M2, respectively) for the June and December contracts.[6] In the majority of cases, the results show insignificant test statistics when M1 is tested versus M2 and significant statistics when M2 is tested

[6] The full set of results can be obtained from the authors on request. The June and December contracts are typically the most heavily traded contracts. It is invariably the case that the only time another month's contract exceeds the trading activity associated with the June and December contracts is when it is the near-month contract.

against M1. This implies that, in most cases, M1 cannot be rejected versus M2, but M2 can be rejected against M1. Hence, the conclusion is that the model should be specified in levels, not in logarithms.

Table 2 reports the non-nested model selection tests to investigate the relative explanatory power of trading volume and open interest: M3 includes the explanatory variables maturity and trading volume, whereas M4 includes the explanatory variables maturity and open interest. In the majority of cases, the results show that M3 is preferred to M4, which means that trading volume has more explanatory power (with respect to volatility) than open interest. This, however, does not necessarily imply that open interest should not be included in the specification. To confirm this, we employ the variable deletion/addition tests (reported in Table 3), in which the null hypothesis is that the coefficient on open interest is not significantly different from zero. In the vast majority of cases, the test statistics are significant, implying that open interest is indeed important and that it provides explanatory power over and above what is provided by trading volume.

Table 4 reports the estimation results for the levels models for the June and December contracts. The table reports the coefficient estimates, their p-values, and the adjusted R^2. Maturity is shown to be rarely significant, whereas trading volume and open interest tend to be significant. The signs for trading volume and open interest are as expected, indicating that an increase in trading volume leads to an increase in volatility, whereas an increase in open interest reduces volatility by increasing market depth. The adjusted R^2 column shows that the explanatory power of the model is reasonable. However, the general specification employed seems to lose explanatory power as we near the end of the period. We comment on this result later in the paper, but it suffices at this stage to say that the explanation of this apparent change is part of ongoing research.

The coefficient estimates' statistical significance are summarized in Table 5. The first three columns identify occurrences of statistical significance at the 95% level (1 indicates significance) without regard for signs. Maturity is shown to be statistically significant 45% of the time, while trading volume is significant 95%

of the time and open interest 73% of the time. The last three columns report the occurrences of both statistical significance and correct sign (1 indicates that both are satisfied). Maturity never has the correct sign for the June and December contracts. It has the right sign (negative) and significance in only 5 percent of the full 131 cases. On the other hand, trading volume and open interest have the correct sign in all cases.[7]

On average, the magnitude of the estimated coefficient on trading volume is over two times larger than that for open interest. Therefore, while open interest represents a statistically significant variable in the explanation of crude oil futures price volatility, its negative influence will be expected to offset only a fraction of the volatility induced by trading volume.

5.2. *Full-period time series analysis*

Table 6 reports the results of the full-period time series analysis, displaying the estimated coefficients and their t statistics, as well as the unadjusted and adjusted coefficient of determination, the standard error of the estimated equation (SE) and the $\chi^2(1)$ test statistic for serial correlation (SC). As noted earlier, the optimal lag structure is represented by the ARDL(5,5,0) model, based on the SBC selection criterion. The signs of the contemporaneous trading volume and open interest are as expected: positive for trading volume and negative for open interest, and both are highly significant. In this specification, only the estimated coefficients on the fourth lag of the dependent variable, β_{14}, and the third lag of trading volume, β_{23}, are insignificant.

It is interesting again to examine the relation between the magnitudes of the trading volume and open interest coefficients, especially since in this analysis the coefficients on lagged trading volume are negative, providing a counter to the positive influence that contemporaneous trading volume has on volatility. The cumulative effect of trading volume (summing the estimated coefficients) is 0.298,

[7] The results for all 131 contracts have a quite similar pattern. For significance only, maturity is significant 41% of the time, volume 90% of the time, and open interest 63% of the time. For significance and sign, maturity satisfies both only 5% of the time, volume 90% of the time, and open interest 63% of the time.

compared to the -0.084 for open interest.[8] Therefore, the relative magnitudes, based on these estimates, show the influence of trading volume on crude oil futures price volatility to exceed that for open interest by over three times, which appears to be in line with the results found in the contract-by-contract analysis.

It is also worth revisiting the earlier discussion of the relation between trading volume and open interest in the context of offsetting effects on volatility. Recalling that trading volume does not unambiguously add to open interest, the change in open interest must be less than the observed trading volume. On any given day, therefore, the offsetting effect of open interest is less than the simple comparison of cumulative coefficient values. Furthermore, it is worth noting that as the maturity of a contract is approached, the influence of open interest on volatility tends to amplify that of trading volume, rather than operate as an offset. This is because as maturity is approached, open interest tends to fall, thus producing a positive effect on volatility through its negative coefficient.

The long-run stability of the selected model specification is supported by the CUSUM and the CUSUMSQ tests, presented in Figures 1 and 2, respectively. Figure 1 shows that the CUSUM of the standardized recursive residuals is insignificantly different from zero (the expectation for the null of constancy), at the 5% level, until very near the end of the study period (mid-July, 2005). The CUSUMSQ reported in Figure 2, on the other hand, shows no significant break with constancy. This suggests that the observed, apparent break with constancy may be due to a systematic, rather than sudden, change in regression coefficients near the end of the period.[9] This result may explain the diminished explanatory power, noted earlier, for the contract-by-contract specification near the end of the

[8] The value for the cumulative effect of trading volume exclude the insignificant coefficient estimate for β_{23}. The coefficient on contemporaneous trading volume is more than double the cumulative effect of the lagged dependent variables (1.345 versus 0.602). However, the cumulative magnitude for all trading volume variables is less than half that for the cumulative lagged dependent variable (0.298 versus 0.602).

[9] Pesaran and Pesaran (1997, p. 116). See also, Brown, et al. (1975, p. 159) for discussion of the interpretation of the CUSUM and CUSUMSQ graphs and suggestions for further analyses to differentiate between the role of changes in regression coefficients and changes in residual variance.

period. Nevertheless, the model specification appears to provide a sound basis for evaluating the roles of both trading volume and open interest over the period.

6. Conclusion

We first established that a model specification in the levels of the explanatory variables is superior to a model that is specified in log-levels and that open interest adds significantly to the explanatory power of a model with maturity and trading volume. Two different estimation approaches were then employed to evaluate the determinants of volatility of crude oil futures prices. In applying both approaches, we used an intra-day range-based measure of volatility, as opposed to an inter-day, close-to-close measure.

The contract-by-contract analysis revealed that trading volume and open interest have significant roles to play in determining price volatility and that they dominate the Samuelson maturity effect. Our results support earlier findings of a positive and significant role for trading volume, and we add to previous findings by showing the importance of open interest in determining crude oil futures price volatility (statistically significant and negative, as expected). Nevertheless, trading volume is estimated to have over twice the magnitude of influence as compared to that for open interest.

The results of the full-period time series analysis also demonstrate the significant role played by open interest in the determination of futures price volatility and further confirms the importance of trading volume. However, it is noted that the offsetting role of open interest is smaller than that of trading volume. The magnitude of the effect of cumulative trading volume on volatility is over three times that for open interest. Moreover, the offsetting influence of open interest switches to an amplifying influence as the contract nears maturity and open interest falls back to zero. The results also suggest that some structural change may have occurred toward the end of the time period under study, 1995-2005. The results collectively suggest that further analysis of these relations and their evolution is warranted, especially as the relations may be changing over time.

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Table 1. Non-Nested Model Selection Tests: Level (M1) vs Log-Level (M2) Models

Contract		*N*	*NT*	*W*	*J*	*JA*	*EN*
Jun-95	M1 vs M2	0.40	0.41	0.42	-0.38	-0.38	0.06
	M2 vs M1	-2.29	-2.05	-1.91	1.98	1.98	1.25
Dec-95	M1 vs M2	-0.25	-0.20	-0.20	0.27	0.20	2.67
	M2 vs M1	-2.53	-2.33	-2.08	2.19	2.05	4.44
Jun-96	M1 vs M2	-0.94	-0.76	-0.74	0.87	0.83	1.54
	M2 vs M1	-0.19	-0.09	-0.09	0.21	0.13	1.31
Dec-96	M1 vs M2	-2.03	-1.81	-1.66	1.82	1.63	13.99
	M2 vs M1	-1.09	-0.95	-0.91	1.09	0.72	12.92
Jun-97	M1 vs M2	-0.19	-0.11	-0.11	0.18	0.17	0.32
	M2 vs M1	-2.46	-2.15	-1.97	2.00	1.93	1.59
Dec-97	M1 vs M2	-1.04	-0.84	-0.82	1.20	0.66	6.45
	M2 vs M1	-0.03	0.05	0.05	0.30	-0.26	6.05
Jun-98	M1 vs M2	-4.25	-3.71	-3.27	3.50	3.54	7.79
	M2 vs M1	1.53	1.46	1.56	-1.61	-1.70	4.06
Dec-98	M1 vs M2	0.22	0.24	0.24	-0.20	-0.21	0.46
	M2 vs M1	-3.21	-2.94	-2.56	2.68	2.68	2.80
Jun-99	M1 vs M2	-0.36	-0.27	-0.27	0.39	0.26	1.69
	M2 vs M1	-1.25	-1.07	-1.03	1.15	1.03	2.08
Dec-99	M1 vs M2	-1.65	-1.45	-1.37	1.47	1.38	2.51
	M2 vs M1	-0.41	-0.32	-0.31	0.43	0.31	1.84
Jun-00	M1 vs M2	-0.21	-0.11	-0.11	0.20	0.19	0.08
	M2 vs M1	-0.99	-0.79	-0.77	0.88	0.88	0.31
Dec-00	M1 vs M2	2.07	1.97	2.18	-2.42	-2.42	2.12
	M2 vs M1	-5.20	-4.76	-3.97	4.64	4.65	7.17
Jun-01	M1 vs M2	-0.92	-0.79	-0.77	0.83	0.83	0.25
	M2 vs M1	-0.44	-0.36	-0.35	0.41	0.41	0.08
Dec-01	M1 vs	-2.26	-2.03	-1.89	1.96	1.93	1.90

	M2						
	M2 vs M1	0.37	0.39	0.39	-0.36	-0.37	0.68
Jun-02	M1 vs M2	-2.09	-1.80	-1.71	1.78	1.76	1.64
	M2 vs M1	0.38	0.41	0.41	-0.35	-0.38	0.65
Dec-02	M1 vs M2	0.94	0.92	0.96	-0.94	-0.98	0.67
	M2 vs M1	-3.51	-3.16	-2.80	2.98	2.91	3.20
Jun-03	M1 vs M2	0.46	0.49	0.50	-0.45	-0.46	0.17
	M2 vs M1	-3.24	-2.84	-2.54	2.54	2.51	2.15
Dec-03	M1 vs M2	0.18	0.24	0.24	-0.17	-0.17	0.37
	M2 vs M1	-2.68	-2.30	-2.11	2.14	2.12	1.84
Jun-04	M1 vs M2	-1.12	-0.83	-0.81	1.01	0.87	3.26
	M2 vs M1	-0.84	-0.58	-0.57	0.80	0.56	3.15
Dec-04	M1 vs M2	1.55	1.48	1.59	-1.70	-1.70	1.14
	M2 vs M1	-4.49	-4.01	-3.44	3.73	3.78	4.72
Jun-05	M1 vs M2	-1.17	-0.71	-0.70	0.93	0.93	1.53
	M2 vs M1	-0.52	-0.21	-0.21	0.46	0.42	1.31
Dec-05	M1 vs M2	0.59	0.60	0.60	-0.49	-0.68	1.12
	M2 vs M1	-1.39	-0.24	-0.24	1.00	1.01	1.33

All test statistics are *t* distributed, with the exception of the *EN,* which is *F* distributed. *N* is the Cox test derived in Pesaran (1974); *NT* is the adjusted Cox test derived in Godfrey and Pesaran (1983); *W* is the Wald-type test proposed by Godfrey and Pesaran (1983); *J* is the Davidson and MacKinnon (1981) test; *JA* is the Fisher-McAleer (1981) test; and *EN* is the encompassing test proposed, *inter alia*, by Mizon and Richard (1986). All of the test statistics have *t* distribution, except for the encompassing test, which is *F* distributed.

Table 2. Non-Nested Model Selection Tests for Trading Volume (M3) vs Open Interest (M4)

Contract		*N*	*NT*	*W*	*J*	*JA*	*EN*
Jun-95	M3 vs M4	1.41	1.43	1.52	-2.00	-2.00	4.00
	M4 vs M3	-18.22	-11.13	-8.82	5.51	5.51	30.31
Dec-95	M3 vs M4	-1.38	-0.92	-0.89	6.06	-6.06	36.73
	M4 vs M3	-11.67	-7.58	-6.36	7.82	-7.82	61.15
Jun-96	M3 vs M4	0.01	0.30	0.31	2.60	-2.60	6.77
	M4 vs M3	-1.96	-0.70	-0.69	2.86	-2.86	8.16
Dec-96	M3 vs M4	-1.35	-0.79	-0.77	5.04	-5.04	25.44
	M4 vs M3	-1.73	-1.06	-1.03	5.11	-5.11	26.09
Jun-97	M3 vs M4	-1.49	-0.84	-0.82	4.50	-4.50	20.24
	M4 vs M3	-1.65	-0.95	-0.92	4.52	-4.52	20.48
Dec-97	M3 vs M4	0.37	0.61	0.62	2.16	-2.16	4.66
	M4 vs M3	-8.74	-2.67	-2.54	3.12	-3.12	9.75
Jun-98	M3 vs M4	-9.80	-3.68	-3.43	4.12	-4.12	16.95
	M4 vs M3	0.71	0.83	0.85	3.05	-3.05	9.32
Dec-98	M3 vs M4	1.21	1.26	1.33	4.75	-4.75	2.57
	M4 vs M3	-28.37	-10.81	-8.88	7.37	-7.37	54.30
Jun-99	M3 vs M4	-0.12	0.19	0.19	3.44	-3.44	11.85
	M4 vs M3	-2.97	-1.51	-1.46	3.86	-3.86	14.89
Dec-99	M3 vs M4	0.96	1.05	1.08	2.89	-2.89	8.34
	M4 vs M3	-22.39	-5.66	-5.14	4.43	-4.43	19.59
Jun-00	M3 vs M4	0.49	0.61	0.63	-0.53	-0.53	0.29
	M4 vs M3	-8.50	-5.62	-4.93	3.36	3.36	11.33
Dec-00	M3 vs M4	1.27	1.34	1.39	-2.00	-2.00	4.00
	M4 vs M3	-86.21	-21.34	-14.69	7.54	7.54	56.92
Jun-01	M3 vs M4	1.35	1.36	1.44	-1.88	-1.88	3.53
	M4 vs M3	-10.94	-6.85	-5.97	4.18	4.18	17.51

Dec-01	M3 vs M4	-13.88	-6.06	-5.42	4.41	-4.41	19.42
	M4 vs M3	-3.46	-1.81	-1.74	3.32	-3.32	11.03
Jun-02	M3 vs M4	0.86	0.93	0.95	2.70	-2.70	7.29
	M4 vs M3	-10.18	-2.74	-2.62	3.52	-3.52	12.39
Dec-02	M3 vs M4	1.61	1.60	1.71	4.03	-4.03	16.28
	M4 vs M3	-159.92	-8.89	-7.73	5.96	-5.96	35.58
Jun-03	M3 vs M4	0.60	0.75	0.77	3.25	-3.25	10.54
	M4 vs M3	-11.61	-4.81	-4.38	4.59	-4.59	21.11
Dec-03	M3 vs M4	1.25	1.29	1.36	3.08	-3.08	9.47
	M4 vs M3	-76.29	-8.54	-7.34	5.18	-5.18	26.82
Jun-04	M3 vs M4	-3.91	-1.06	-1.04	2.63	-2.63	6.90
	M4 vs M3	0.48	0.63	0.64	2.19	-2.19	4.82
Dec-04	M3 vs M4	1.77	1.75	1.91	-3.08	-3.08	9.52
	M4 vs M3	-25.29	-12.32	-9.72	6.30	6.30	39.52
Jun-05	M3 vs M4	1.04	1.07	1.11	-1.49	-1.49	2.21
	M4 vs M3	-8.64	-3.64	-3.41	2.86	2.86	8.15
Dec-05	M3 vs M4	-0.39	0.37	0.37	0.66	-0.66	0.44
	M4 vs M3	-0.03	0.42	0.43	0.62	-0.62	0.39

All test statistics are *t* distributed, with the exception of the *EN,* which is *F* distributed. *N* is the Cox test derived in Pesaran (1974); *NT* is the adjusted Cox test derived in Godfrey and Pesaran (1983); *W* is the Wald-type test proposed by Godfrey and Pesaran (1983); *J* is the Davidson and MacKinnon (1981) test; *JA* is the Fisher-McAleer (1981) test; and *EN* is the encompassing test proposed, *inter alia*, by Mizon and Richard (1986). All of the test statistics have *t* distribution, except for the encompassing test, which is *F* distributed.

Table 3. Variable Deletion/Addition Tests as Applied to Open Interest

Contract	LM ($\chi^2(1)$)	LR ($\chi^2(1)$)	F
Jun-95	4.00*	4.20*	4.00
Dec-95	20.64*	28.41*	36.73*
Jun-96	6.36*	6.88*	6.77*
Dec-96	16.97*	21.59*	25.44*
Jun-97	14.50*	17.89*	20.24*
Dec-97	4.59*	4.85*	4.66*
Jun-98	12.95*	15.49*	16.95*
Dec-98	15.76*	19.63*	22.57*
Jun-99	9.98*	11.40*	11.85*
Dec-99	7.59*	8.33*	8.34*
Jun-00	0.31	0.31	0.29
Dec-00	4.00*	4.20*	4.00
Jun-01	3.57	3.72	3.53
Dec-01	14.30*	17.38*	19.42*
Jun-02	6.77*	7.37*	7.29*
Dec-02	12.66*	15.00*	16.28*
Jun-03	9.12*	10.28*	10.54*
Dec-03	8.40*	9.34*	9.46*
Jun-04	6.45*	7.01*	6.90*
Dec-04	8.39*	9.38*	9.52*
Jun-05	2.31	2.37	2.21
Dec-05	0.48	0.49*	0.44

* Significant at the 5% level. LM and LR statistics (both with a χ^2 distribution) and an F-statistic. The null hypothesis in all cases is that the coefficient on the deleted or added variable is zero. In the case of the variable deletion test, we start from a model that contains all three explanatory variables and impose the restriction that the coefficient on open interest is zero. In the case of the variable addition test, we start from a model that has maturity and volume as the explanatory variables, then measure the effect of adding open interest as an explanatory variable.

Table 4. Results for the Contract-by-Contract Analysis

Contract	*m*	p-value	*v*	p-value	*o*	p-value	$\overline{R}^2$
Jun-95	0.039	0.724	0.595	0.000	-0.133	0.052	0.44655
Dec-95	0.490	0.000	0.725	0.000	-0.324	0.000	0.63766
Jun-96	0.519	0.702	4.260	0.007	-2.290	0.013	0.18439
Dec-96	1.140	0.016	2.430	0.000	-1.320	0.000	0.44948
Jun-97	0.844	0.033	1.510	0.000	-0.757	0.000	0.38192
Dec-97	0.272	0.520	1.200	0.003	-0.587	0.037	0.15054
Jun-98	2.060	0.183	3.320	0.004	-2.940	0.000	0.26417
Dec-98	0.733	0.127	2.260	0.000	-0.894	0.000	0.58052
Jun-99	0.747	0.046	0.938	0.000	-0.383	0.001	0.25433
Dec-99	1.560	0.009	1.390	0.000	-0.503	0.006	0.30415
Jun-00	0.556	0.244	0.998	0.002	-0.124	0.596	0.22756
Dec-00	3.120	0.000	3.430	0.000	-0.577	0.053	0.59262
Jun-01	0.751	0.007	1.180	0.000	-0.359	0.068	0.29709
Dec-01	0.746	0.776	4.840	0.002	-3.300	0.000	0.35282
Jun-02	1.100	0.072	1.500	0.001	-0.695	0.010	0.18668
Dec-02	0.063	0.805	0.862	0.000	-0.372	0.000	0.52933
Jun-03	3.290	0.000	1.800	0.000	-0.592	0.002	0.43892
Dec-03	1.010	0.015	1.130	0.000	-0.336	0.004	0.36296
Jun-04	0.752	0.036	0.436	0.035	-0.180	0.012	0.13113
Dec-04	0.459	0.229	1.090	0.000	-0.236	0.004	0.53666
Jun-05	0.459	0.217	0.589	0.007	-0.113	0.145	0.12387
Dec-05	0.383	0.144	0.098	0.538	-0.035	0.510	-0.0182

m is maturity, *v* is trading volume, and *o* is open interest.

Table 5. Measures of Correct Sign and Significance

	Significance Only			Sign and Significance		
	m	*v*	*o*	*M*	*v*	*o*
Jun-95	0	1	0	0	1	0
Dec-95	1	1	1	0	1	1
Jun-96	0	1	1	0	1	1
Dec-96	1	1	1	0	1	1
Jun-97	1	1	1	0	1	1
Dec-97	0	1	1	0	1	1
Jun-98	0	1	1	0	1	1
Dec-98	0	1	1	0	1	1
Jun-99	1	1	1	0	1	1
Dec-99	1	1	1	0	1	1
Jun-00	0	1	0	0	1	0
Dec-00	1	1	0	0	1	0
Jun-01	1	1	0	0	1	0
Dec-01	0	1	1	0	1	1
Jun-02	0	1	1	0	1	1
Dec-02	0	1	1	0	1	1
Jun-03	1	1	1	0	1	1
Dec-03	1	1	1	0	1	1
Jun-04	1	1	1	0	1	1
Dec-04	0	1	1	0	1	1
Jun-05	0	1	0	0	1	0
Dec-05	0	0	0	0	0	0
Percent	0.45	0.95	0.73	0	0.95	0.73
Number	10	21	16	0	21	16

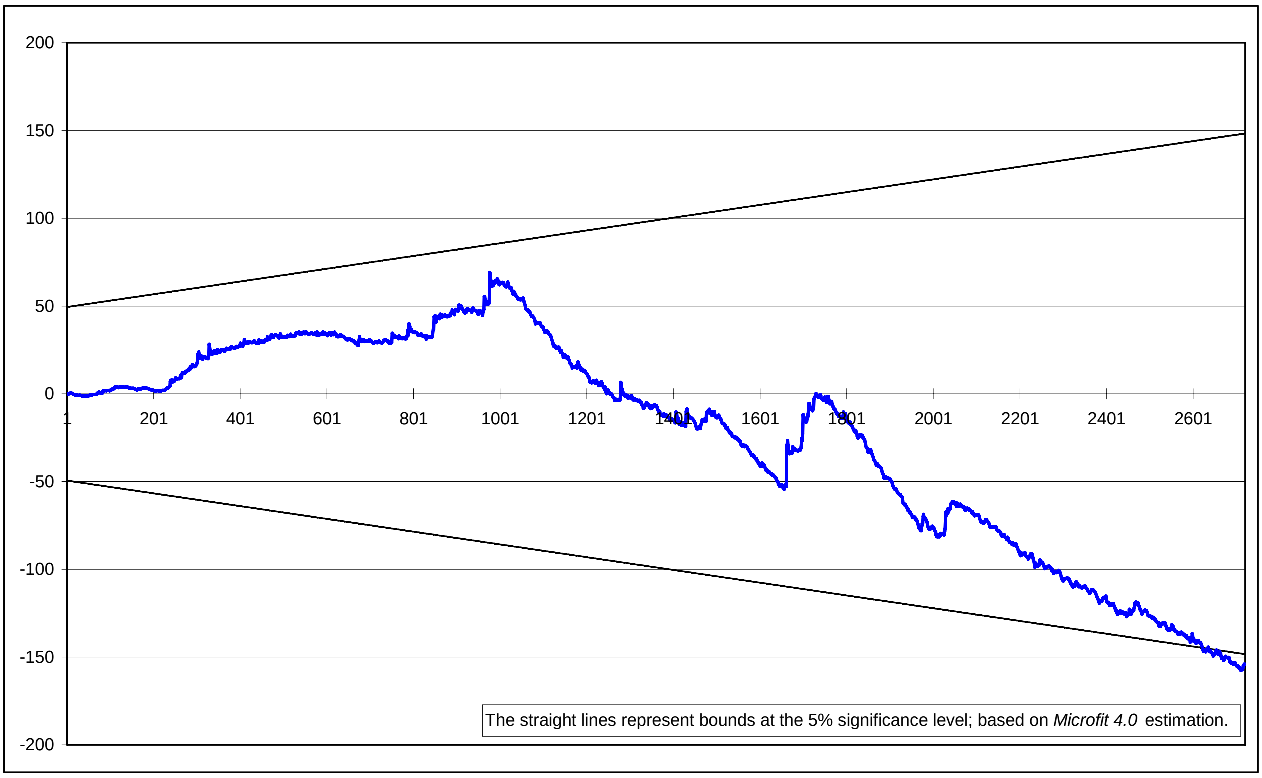
In the first three columns, a 1 indicated statistical significance at 5%, without regard to sign. In the last three columns, a 1 indicates both statistical significance and the correct sign.

Table 6. Full-Period Time Series Results for the ARDL(5,5,0) Model

Coefficient/Statistic	Estimated Value	t Statistic
β_0	0.819	3.12
β_{11}	0.209	10.98
β_{12}	0.204	10.45
β_{13}	0.091	4.57
β_{14}	0.025	1.29
β_{15}	0.098	5.13
β_{20}	1.345	30.28
β_{21}	-0.453	-8.52
β_{22}	-0.218	-4.07
β_{23}	-0.038	-0.72
β_{24}	-0.112	-2.07
β_{25}	-0.264	-5.15
β_{30}	-0.084	-3.52
R^2	0.36	
$\overline{R}^2$	0.36	
SE	4.09	
SC	2.88	

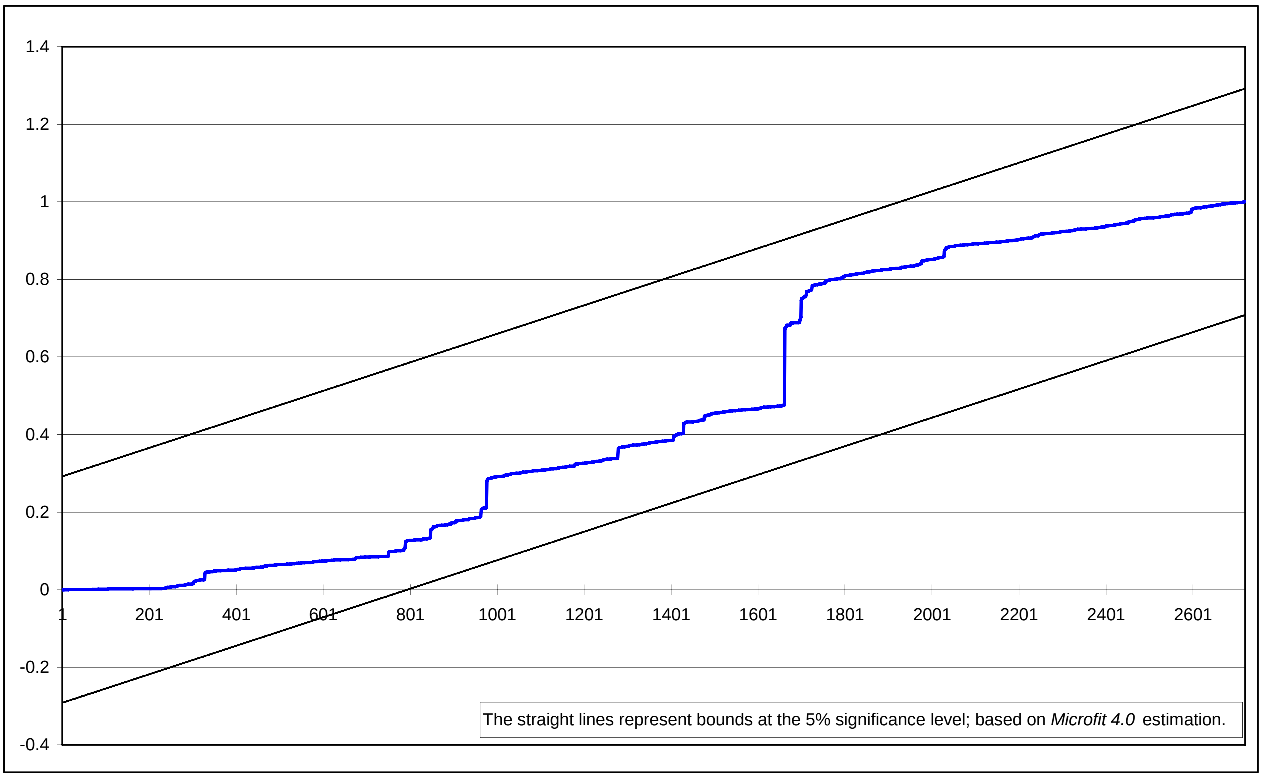
β_0 is the constant term, β_{11} - β_{15} are coefficients on lagged volatility (the dependent variable), β_{20} - β_{25} are coefficients on contemporaneous and lagged trading volume, and β_{30} is the coefficient on contemporaneous open interest. R^2 and $\overline{R}^2$ are unadjusted and adjusted coefficients of determination, respectively, *SE* is the standard error of the estimated equation, and *SC* is the $\chi^2(1)$ test statistic for serial correlation.

Figure 1. Cumulative Sum of Standardized Recursive Residuals: ARDL(5,5,0) Model.



The horizontal axis represents 2739 daily observations over the period. The CUSUM crosses the 5% lower bound in mid-July, 2005.

Figure 2. Cumulative Sum of Squared Standardized Recursive Residuals: ARDL(5,5,0) Model



The horizontal axis represents 2739 daily observations over the period.

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