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APPLIED COMMODITY PRICE ANALYSIS, FORECASTING AND MARKET RISK MANAGEMENT

**The Price Adjustment Process and Efficiency of Grain
Futures Markets Implied by Return Series of Various
Time Intervals**

by

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THE PRICE ADJUSTMENT PROCESS AND EFFICIENCY OF GRAIN FUTURES MARKETS
IMPLIED BY RETURN SERIES OF VARIOUS TIME INTERVALS

Shi-Miin Liu and Sarahelen R. Thompson*

Price efficiency of markets is the focus of numerous empirical economic investigations. Autocorrelation analyses, trading rule techniques, and model building methods have been employed by previous studies to address the issue of market efficiency. However, each of the three methods has deficiencies with respect to proving or disproving the market efficiency hypothesis.

Danthine (1977) points out that zero-autocorrelation analyses are the simultaneous tests of market efficiency, perfect competition, risk neutrality, constant return to scale, etc. Interpreting the results using trading rules is also difficult since no probabilistic statement can be made as to whether the produced profits are significantly different from what would be obtained from applying the same rules to a random series (Cargill-Rausser, 1975). The problem of assessing futures market performance through ARIMA or econometric model testing is that a convincing way to deal with costs of information, risk aversion, irrational market participants, and alternative transaction costs has not been developed. These factors will cause futures prices to be biased expectations of subsequent spot prices (Rausser-Carter, 1983), and make the assessment of the performance of futures markets ambiguous. Moreover, Gerlow-Irwin (1988) demonstrate that statistical criteria (e.g., mean square error) commonly used to evaluate the efficiency of speculative markets are powerless because the crucial element of market timing is not contained in those criteria. Therefore, employing a different approach to the investigation of market efficiency is warranted.

Traditional testing of the market efficiency hypothesis is based on the assumption that the market price is formed by instantaneously equilibrating the supplies and demands of all traders. There are no frictions (i.e., information, decision, and transaction costs) interrupting the trading process. Under these assumptions, the issue of market efficiency can be explored through the examination of observed price behavior. However, contrary to these assumptions, buy and sell orders of traders are endogenous to the market system, and market outcomes are dependent on institutional arrangements in the real world. By examining the trading of twelve technical systems for a portfolio of twelve commodities from 1978 to 1984, Lukac-Brorsen-Irwin (1988) conclude that disequilibrium models are a better description of short-run futures price movements than the random walk model. Consequently, observed trading prices differ from underlying equilibrium values that would prevail in frictionless surroundings. The persistence of a discrepancy between observed prices and equilibrium values is associated with non-instantaneous price adjustment in an dynamic market environment. Markets may be portrayed by general processes that allow a finite period of adjustment and transactions at the current (non-equilibrium) market prices.

Institutional factors have an impact on the price adjustment process.

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Three major types of price-adjustment delays are discussed by Cohen-Maier-Schwartz-Whitcomb (CMSW) (1986, p.114): (1) transaction price adjustments lag quotation price adjustments; (2) specialist-dealers impede quotation price adjustments; and (3) there are quotation price adjustment lags for individual traders. In addition, noise trading, scalping in futures markets, has an important impact on the price adjustment process. Noise trading is contrasted with information trading, and is essential to the existence of liquid markets (Black, 1986). The noise results from both the transitory liquidity needs of traders and investors, and from errors in the analysis and interpretation of information (i.e., the inability of market participants to accurately recognize market forces). Noise trading may cause delay as well as over-reaction of the observed prices to their underlying values. Techniques employed to measure trading noise, or liquidity costs, were proposed by Roll (1984), Thompson (1984), and Brorsen-Nielsen (1986). After comparing these techniques, Thompson-Waller (1988) suggest that the most appropriate measure of liquidity in commodity futures markets is the average of the absolute value of price changes.

The objectives of this research are to: 1) explore the price adjustment process and efficiency of corn and oats futures markets by using an approach developed by Amihud-Mendelson (1987); 2) investigate the impact and implications of interval effects on the price-adjustment process using different return series; and 3) compare the price adjustment process and efficiency in corn and oats futures markets to identify similarities as well as differences in their market performance.

Models and Data

It is assumed in this study that the time path of underlying equilibrium values of grain futures follows a lognormal distribution, and that observed futures prices adjust continuously toward their current equilibrium values. Although it is unknown how far away an observed price is from its equilibrium value, the farther the price of a grain futures moves from its value, the faster it will tend to move back (Black, 1986). Let V_t be the true price (value) of a grain futures contract in a frictionless environment at time t , and P_t the observed price. For the purpose of simplicity, both V_t and P_t are in logarithm forms. Then, the observed return is defined by $R_t = P_t - P_{t-1}$.

Following Amihud-Mendelson's (1987) price adjustment model, the difference between V_t and P_t is attributable to noise. The relationship among the true value, observed price, and noise is described by equation (1).

$$P_t - P_{t-1} = g \cdot [V_t - P_{t-1}] + u_t, \quad (1)$$

where g is the price adjustment coefficient, satisfying $0 < g < 2$, and, u_t is a "white noise" sequence of i.i.d. random variables with zero mean and finite variance σ^2 . That g has a value between 0 and 2 is implicit in the model, and will be shown later. The adjustment coefficient g captures the effect of friction factors which make the observed price deviate from its value in the real world market. When $g = 0$, observed price movements are unrelated to changes in underlying value. $0 < g < 1$ represents partial price

adjustment, and $g > 1$ represents over-reaction of the market. A unit adjustment coefficient ($g = 1$) reflects full price adjustment despite noise, and $P_t = V_t + u_t$.

Suppose the logarithms of commodity futures value conform to a random walk process as follows.

$$V_t = V_{t-1} + e_t + m, \quad (2)$$

where m is the expected return drift and e_t is an i.i.d. random variable, independent of u_t , with zero mean and finite variance v^2 . The difference of $(V_t - V_{t-1})$ will be called the value return. Usually, m is assumed equal to zero for commodity futures returns (Black, 1976).

From (1) and (2), it follows that

$$P_t = g \cdot \sum_{i=0}^{\infty} (1-g)^i V_{t-i} + \sum_{i=0}^{\infty} (1-g)^i u_{t-i}, \quad (3)$$

and

$$R_t = g \cdot \sum_{i=0}^{\infty} (1-g)^i (e_{t-i} - u_{t-i-1}) + u_t. \quad (4)$$

According to (4), the observed return variance is equal to

$$\text{Var}(R_t) = g^2 \sum_{i=0}^{\infty} (1-g)^{2i} (v^2 + \sigma^2) + \sigma^2. \quad (5a)$$

After rearrangement, equation (5a) yields

$$\text{Var}(R_t) = \frac{g}{2-g} v^2 + \frac{2}{2-g} \sigma^2. \quad (5b)$$

The first term on the right-hand-side of (5b) expresses the contribution of the value return (v^2) to the observed return variance, and the second represents the contribution of the noise. The contribution of noise to the observed return variance is an increasing function of both the noise variance σ^2 and the adjustment coefficient g . Since the price disturbance in one period is transferred by the adjustment process to the following period's price, the larger the adjustment coefficient, the larger the transmission of the noise to the observed return variance. In general, the observed return variance may either over-estimate or under-estimate the value return variance, and the relationship between the two is an empirical question.

A modification of Thompson's (1984) technique is used to measure trading noise. To suit the assumption of lognormal distribution of the true value returns, the average of the absolute value of returns is used to measure noise. A simulation analysis based on the model assumptions

[equations (1) and (2)] has shown the measure to be robust¹. Hence, the equation empirically used to describe the variance of observed returns is as follows.

$$\text{Var}(R_t) = \frac{g}{2-g} v^2 + \frac{2}{2-g} \overline{|R_t|^2}. \quad (6)$$

Since the value return variance v^2 is unknown, the first term on the right-hand-side of equation (6) may be estimated with a constant, or intercept term, in regression estimation. Both linear and nonlinear regression methods are employed. In linear estimation, the implied estimate for adjustment factor g may be calculated after obtaining an estimate for the coefficient $(2/2-g)$ of the second term of equation (6). In contrast, nonlinear estimation will reveal directly the price adjustment estimate as well as the standard error and 95% confidence intervals of g . Estimates of the g may then be used to evaluate price efficiency.

According to Black's (1986) criteria, a market may be judged efficient if price is within a factor of twice its value, i.e., the market price is between half and twice the underlying equilibrium value. Amihud-Mendelson interpret Black's criteria as $0 < g < 2$. However, if the noise term, u_t , is ignored and g is set to equal .5 and 2 respectively in equation (1), Black's idea of efficient markets is implied ($.5 V_t < P_t < 2 V_t$). The adoption of this asymmetric constraint for g ($.5 < g < 2$) is justified because noise trading alone is considered to affect the variance of returns in the model used in this study. Most institutional factors which have an impact on the price adjustment process cause partial adjustment of the observed prices to their underlying values (CMSW, 1986, P.114). Moreover, institutional price-adjustment delays, to a certain extent, are inevitable. Institutional factors will usually bias g towards values less than 1. Therefore, only values of g less than .5 will be considered to represent inefficiency. In contrast, noise trading may cause partial adjustment as well as over-reaction of the market. Excess amounts of noise trading will cause market inefficiency. Of course, the most intuitive, or acceptable, standard to evaluate market performance is $g=1$. But this value is not expected in most empirical cases.

A Box-Jenkins' type ARMA(1,1) model of the return series may also be built based on Amihud-Mendelson's model from equations (1) and (2)². Equation (1) can be rewritten as: $[1-(1-g)B] P_t = g V_t + u_t$, where B is a backward operator. Equations (1) and (2) are combined to form:

$$[1-(1-g)B] P_{t-1} = g V_{t-1} + u_{t-1}, \text{ and} \quad (7)$$

$$[1-(1-g)B](1-B) P_t = g e_t + g m + u_t - u_{t-1}. \quad (8)$$

m is set equal to zero. Then, from (7) and (8), we obtain

$$[1-(1-g)B] R_t = g e_t + u_t - u_{t-1}. \quad (9)$$

Since the terms on the right-hand-side of equation (9) are composed of noise of present and previous periods, they can be described by a moving-average process. Equation (9) therefore can be rewritten as an ARMA (1,1) process:

$$[1-(1-g)B] R_t = \mu_t - b \mu_{t-1}, \quad (10)$$

where μ_t is a white noise. An AR (1) process is shown on the left-hand-side of equation (9), and a MA (1) process is indicated on the right hand side.

The constraint for g , $0 < g < 2$, in Amihud-Mendelson's model is implicit in the associated ARMA (1,1) process. If g is greater than 2 or less than 0, the absolute value of $(1-g)$ is greater than 1 and the ARMA (1,1) process is explosive (Granger-Newbold, 1986, p.39). In other words, observed prices of grain futures will increasingly deviate from their underlying equilibrium, and never adjust or converge to equilibrium.

After fitting an ARMA (1,1) model to a return series, the price adjustment factor g can be obtained directly from the estimated AR (1) coefficient, $(1-g)$.³ Price adjustment factors estimated from the methods summarized in equations (6) and (10) will be compared. Apparent differences in g may indicate (among other things) that the mean absolute return is not a proper measure of trading noise.

Data from all corn and oats futures contracts (March, May, July, September, and December contracts) expiring in 1986 traded on the Chicago Board of Trade are employed in this study. Two basic types of data analyzed are daily closing prices and the intraday prices. The intervals over which returns are considered are weekly and daily return series generated from closing prices; and one-hour, half-hour, 15-minute, 5-minute, and tick return series generated from intraday prices. Weekly futures returns are calculated from Wednesday-to-Wednesday closing prices. Daily futures returns are simply the differences of log closing prices. For intraday series, say the quarter-hour series, prices are recorded at each fifteen minutes from 9:45 a.m. to 1:00 p.m. for each trading day. Then, returns are computed. If no price is recorded exactly at the ending points of the time intervals, tick prices within a selected range and nearest to the ending points are used⁴. The intraday return series also exclude opening and/or closing prices ranges. No overnight changes are included in the intraday return series. Both near and distant observation periods in terms of time to maturity of price data are considered for each contract analyzed⁵.

It is expected that most estimates of price adjustment factors will have a value between 0.5 and 2.0, reflecting the attainment of Black's criteria for efficiency in grain futures markets. Based on information provided by Working (1967) on the intervals over which professional speculators hold futures positions, the behavior of tick return series may be associated mainly with scalpers' trading activities; the return patterns of 5-minute, quarter-hour, half-hour, and one-hour series with day traders' actions; and the movements of daily and weekly series with position traders' activities. Therefore, the price adjustment factors estimated for series over these intervals may be associated with the competitive performance of the speculators hypothesized to influence trading over these intervals.

Results

A pair of "return variance" and "the mean absolute return" are acquired from each return series described above and considered as one observation in the regression estimation of equation (6). Since two return series (near and distant periods) are generated for each futures contract expiring in 1986, the number of observations used to estimate equation (6) for corn and oats is equal to twice the number of traded contracts (2 * 5 contracts for both corn and oats). To acquire price adjustment estimates under nonlinear regression estimation of equation (6), the intercept estimates obtained from linear estimation are used as initial values in nonlinear estimation. Nonlinear estimates of g produced with these starting values are identical to linear estimate. The standard error and the 95% confidence interval of g are directly given in nonlinear estimation. The regression results of equation (6) for corn and oats are presented in Tables 1 and 2, respectively.

For the corn futures return series, trading noise as measured by the mean absolute return is important in explaining the variation of returns for all series, although to a lesser extent for the weekly returns, as judged by the adjusted R^2 from estimation of equation (6). Several return series for corn exhibit partial adjustment of observed prices to their underlying equilibrium values ($g < 1$), although the quarter-hour return series suggests an almost immediate adjustment of the market ($g \approx 1$). Figure 1 plots the price adjustment estimates for corn obtained from nonlinear estimation and their asymptotic 95% confidence intervals. For the 5-minute, quarter-hour, half-hour, and one-hour corn series, the price adjustment estimates do not significantly differ from one; therefore the hypothesis of instantaneous price adjustment or perfect market efficiency cannot be rejected. The tick price adjustment for corn of .291 is the only case where efficiency can be rejected using Black's criteria ($.5 < g < 2$). The negative estimate of g for the weekly series is not significantly different from .5, and is therefore within Black's efficiency range.

The regression results for oats also indicate that the return variance in oats futures contracts is strongly affected by trading noise. However, the pattern of implied price adjustment factors estimated for oats differ from those for corn. Fewer series imply partial price adjustment as judged by the criteria that all regression estimates of g differ significantly from .5. Two series (5-minute and quarter-hour) imply over-reaction of the market as judged by a failure to reject the null hypothesis of $g=1.5$. Values of g decline steadily between 5-minute and weekly intervals suggesting over-reaction in the short-run but partial adjustment over longer periods. Nevertheless, the oats futures market must be judged efficient according to Black's criteria. These results for oats are also depicted in Figure 2.

Table 3 presents the price adjustment estimates obtained from both nonlinear estimation of equation (6) and ARMA (1,1) estimation with 95% confidence intervals.⁶ The proposed standard to compare these price adjustment estimates is that if at least one point estimate derived from the two methods is within the confidence interval derived from the other method, the two estimates are considered close. Using this criteria, the consistency of the price adjustment estimates and the robustness of using the mean absolute return as the measure of trading noise can be analyzed.

In corn futures contracts, inefficient price adjustment estimates ($g <$

Table 1. Regression Results of Equation (6) Using Returns of Corn Futures Contracts Expiring in 1986

	Tick Return	Five- Minute Intraday Return	Quarter- Hour Intraday Return	Half- Hour Intraday Return	One- Hour Intraday Return	Daily Return	Weekly Return
Linear Estimation							
$b = (2/2 - g)$	1.170 (.041)*	2.581 (.600)*	1.938 (.319)*	1.583 (.318)*	1.792 (.164)*	1.683 (.077)*	.759 (.260)*
Adjusted R-Square	.989	.660	.800	.726	.930	.982	.455
Degrees of Freedom	9	9	9	9	9	9	9
Implied g	.291	1.225	.968	.737	.884	.812	-.635
Nonlinear Estimation^a							
g	.291 (.060) ^b	1.225 (.180)	.968 (.169)	.736 (.254)	.884 (.102)	.812 (.025)	-.635 (.523)
Upper ^c Bound of g	.430	1.641	1.359	1.321	1.119	.869	.571
Lower Bound of g	.151	.809	.577	.152	.648	.754	-1.841

*: Significant at 5% level. The standard errors of estimated parameter are in the parentheses.

- a. The nonlinear estimation uses intercept estimates obtained from linear method as an initial value.
- b. Asymptotic standard error of the estimated g.
- c. The upper and lower bounds of g combined provide an asymptotic 95% confidence interval for g.

Table 2. Regression Results of Equation (6) Using Returns of Oats Futures Contracts Expiring in 1986

	Tick Return	Five- Minute Intraday Return	Quarter- Hour Intraday Return	Half- Hour Intraday Return	One- Hour Intraday Return	Daily Return	Weekly Return
Linear Estimation							
$b = (2/2 - g)$	1.968 (.185)*	8.820 (2.281)*	3.289 (.664)*	2.977 (.353)*	2.297 (.245)*	1.679 (.098)*	1.651 (.138)*
Adjusted R-Square	.926	.608	.723	.886	.906	.970	.940
Degrees of Freedom	9	9	9	9	9	9	9
Implied g	.984	1.773	1.392	1.328	1.129	.809	.789
Nonlinear Estimation^a							
g	.984 (.096) ^b	1.773 (.046)	1.392 (.088)	1.328 (.057)	1.129 (.093)	.809 (.044)	.789 (.060)
Upper ^c Bound of g	1.204	1.878	1.595	1.460	1.344	.909	.926
Lower Bound of g	.763	1.668	1.189	1.196	.915	.708	.651

*: Significant at 5% level. The standard errors of estimated parameter are in the parentheses.

- a. The nonlinear estimation uses intercept estimates obtained from linear method as an initial value.
- b. Asymptotic standard error of the estimated g.
- c. The upper and lower bounds of g combined provide an asymptotic 95% confidence interval for g.

Plots of Price Adjustment Estimates Obtained from Nonlinear Regression Estimation with 95% Confidence Intervals.

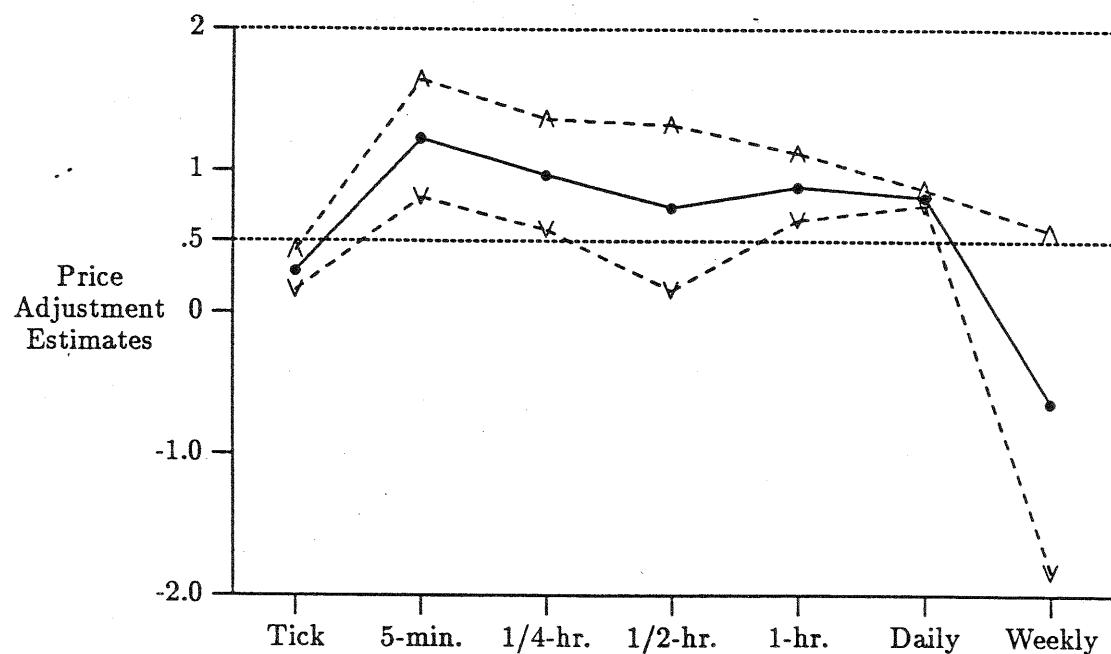


Figure 1: Corn

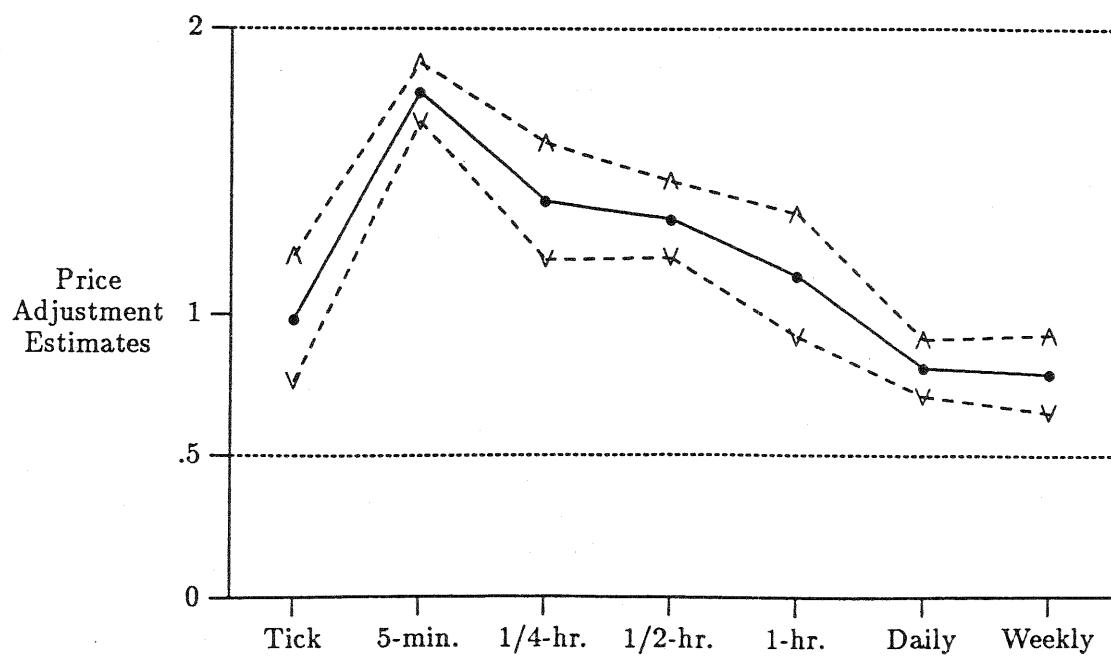


Figure 2: Oats

Table 3. Comparisons of Price Adjustment Estimates Derived From Both Nonlinear Estimation of Equation (6) and ARMA (1,1) Estimation

	Tick Return	Five- Minute Intraday Return	Quarter- Hour Intraday Return	Half- Hour Intraday Return	One- Hour Intraday Return	Daily Return	Weekly Return
Corn							
ARMA(1,1) ^a	.479	1.384	1.153	1.179	1.084	.261	1.320
Upper Bound	.553	1.808	1.928	2.013	4.706	.626	2.425
Lower Bound	.405	.960	.378	.345	-2.538	-.104	.215
Eq. (4.6) ^b	.291	1.225	.968	.737	.884	.812	-.635
Upper Bound	.430	1.641	1.359	1.321	1.119	.869	.571
Lower Bound	.151	.809	.577	.152	.648	.754	-1.841
Oats							
ARMA(1,1)	1.114	.998	1.278	.878	1.079	.703	1.000
Upper Bound	1.769	2.042	1.928	1.434	2.731	19.824	3.368
Lower Bound	.459	-.046	.628	.322	-.573	-18.418	-1.368
Eq. (4.6)	.984	1.773	1.392	1.328	1.129	.809	.789
Upper Bound	1.204	1.878	1.595	1.460	1.344	.909	.926
Lower Bound	.763	1.668	1.189	1.196	.915	.708	.651

a. ARMA (1,1) estimation is explained in endnotes 3 and 6.

b. Nonlinear regression results are the same as those presented in Tables 1 and 2.

.5) from the tick return series are acquired under both estimation methods, but they are not close. The price adjustment estimates from the daily and weekly series in corn are also not close. Nonlinear regression estimation yields an efficient daily price adjustment estimate in corn ($g=.812$), but the ARMA (1,1) model provides an inefficient estimate ($g=.261$). The difference between the weekly price adjustment estimates ($g=-.635$ and $g=1.320$) is even larger. On the other hand, in oats futures contracts, the price adjustment estimates obtained from both methods are close and efficient across all time interval groups. Since the price adjustment estimates in 11 out of 14 corn and oats return series are judged close, the mean absolute value of observed returns appears to be an imperfect, but acceptable, measure of trading noise.

Estimates of g based both on the regression and the ARMA (1,1) estimation methods generally support the conclusion of market efficiency in corn and oats futures contracts insofar as most estimates of g either fall in the range of $.5 < g < 2$, or, under the regression method, confidence intervals for g include values within this range. The most significant exception to this general finding is the corn return series on a tick basis for which both the confidence intervals provided by regression estimation and the ARMA (1,1) estimates suggest inefficient partial price adjustment ($g < .5$).

Conclusions and Implications

These results generally support a conclusion of market efficiency in corn and oats futures contracts according to Black's criteria. The only exception is the tick return series in corn futures market, which exhibits unacceptably low partial price adjustment. Thus, the performance of scalpers in corn futures market warrants further investigation. The competitiveness and/or the information processing ability of day traders in corn futures markets is supported by the finding that price adjustment estimates do not differ significantly from one in the 5-minute, quarter-hour, half-hour, and one-hour series. The performance of position traders in corn futures markets is questionable because although regression based estimates of price adjustment factors for daily and weekly returns fall within Black's range, regression and ARMA (1,1) point estimates of price adjustment factors for these series suggest inefficient partial price adjustment.

For oats, all categories of speculators appear to perform well insofar as all price adjustment estimates fall within Black's range. This is particularly noteworthy since oats futures are relatively thinly traded, and may therefore be suspected of having greater performance problems with respect to information processing. It is possible that due to a lack of liquidity in oats futures, little noise trading occurs, and market prices, although less frequently observed, more fully reflect equilibrium values.

Endnotes

1. A fortran program describing the behavior of observed price and the underlying value is written according to equations (1) and (2). Given different price-adjustment factors (g), initial log values and prices (V_0, P_0), and the standard deviations of noise and value return (σ, v), the difference between the mean absolute return from a sample series with 2000 observations and the sample noise σ has been examined. The difference is small and depends on the level of g chosen for simulation.
2. The derivation of an ARMA (1,1) process for observed return series from Amihud-Mendelson's (1987) model is suggested by Paul Newbold.
3. Suppose a_1 is the estimated coefficient of AR (1) in equation (10). Then, the implied price adjustment estimate g of a return series will equal to $(1+a_1)$. Significance of the estimated AR (1) coefficients may indicate the deviation of price process from a frictionless instantaneous adjustment. In contrast, the price adjustment estimate is near to 1 if its counterpart a_1 is insignificantly different from zero.
4. If no price is found within the selected range of an ending point, a zero return is assigned to that point. The return for the next period is calculated from the ending point of the previous non-zero return.
5. For tick and 5-minute data, "near" is 1 month from maturity, and "distant" is 5 months; for quarter-hour data, near is 1-2 months, and distant is 5-6 months; for half-hour data, near is 1-3 months, and distant is 5-7 months; and for one-hour, daily, and weekly returns, near is 1-4 months, and distant is 5-12 months from maturity. In the daily and weekly return series, observations for some of the contracts analyzed are from overlapping time periods.
6. A representative price adjustment estimate derived from the ARMA (1,1) estimates for each return series analyzed for a specific time interval return group is calculated by taking the mean of $g=(1+a_1)$ when a_1 is significant, and $g=1$ when a_1 is insignificant in a series. The 95% confidence interval of each estimated g can be built by using the estimate, standard error of g (i.e., the standard error of the estimated AR (1) coefficient), and an appropriate t-value. Then, the average of the confidence intervals within a time interval group provides the upper and lower bounds for the representative price adjustment estimate. Complete price adjustment estimates obtained from the ARMA (1,1) process for each corn and oats futures contract are not presented due to page constraints.

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