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# MEAN REVERSION IN AGRICULTURAL FUTURES PRICES

Thomas E. Jackson, Carl R. Zulauf, and Scott H. Irwin*

Random walk or martingale stochastic price processes have been the dominant paradigm of price movements in security and commodity markets (LeRoy). However, recent research (Ceccheti, et al.; DeBondt and Thaler; Fama and French; Poterba and Summers; Stein), suggests that price movements in security markets may follow a "mean reversion" process. In a mean reversion process, price will return to its underlying value (i.e., its mean) whenever speculative forces push the price sufficiently far from its mean (Poterba and Summers).

This study extends the investigation of mean reversion price processes by evaluating the existence of mean reversion in the futures prices of seven agricultural commodities: corn, soybeans, soymeal, soyoil, live hogs, live cattle, and feeder cattle. These commodities are selected because they comprise three important agricultural production spreads which also are tested for mean reversion:

1) cattle feeding - inputs of feeder cattle and corn to produce fed cattle;
2) hog feeding - inputs of corn and soymeal to produce hogs; and
3) soybean processing - input of soybeans to produce soymeal and soyoil.

The methodology and data used to test for mean reversion are discussed in the next section, followed by an analysis of the results for a market timing test of mean reversion. Next, net trading returns generated by a simple trading rule based on mean reversion are evaluated. The relationship between the historical moving average of prices used to estimate the mean price and the cost of production published by the U.S. Department of Agriculture is then investigated. Last, conclusions and implications are drawn.

## An Overview of Mean Reversion Price Processes

If price change is determined by a mean reverting price process, price will return to its mean value over time whenever market events force the price away from its mean. The basic concept of return to the mean implies that price movement is not random once the price differs from the mean. Instead of the expected price change being zero as with a random walk or martingale price process, the expected price change will be in the direction back towards the mean. Furthermore, mean reversion suggests that the magnitude of the expected price change is not independent of the market situation, but is positively related to the distance from the mean. These comparisons between a random walk and mean reversion price processes are illustrated in Figure 1.

If price change follows a mean reversion process, a naive forecasting technique of comparing the current price of a traded asset with its mean price should predict realized price changes. In this study of agricultural futures prices, this naive forecasting technique can be represented as a binary forecast variable $F_t$, such that:

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(1) $F_t = 1$ if $MP_t > FP_t$ (futures price should increase)
(2) $F_t = 0$ if $MP_t \leq FP_t$ (futures price should decrease)

where: $MP_t$ = mean price at the beginning of the trading period
$FP_t$ = futures price at the beginning of the trading period
$t$ = time

This naive mean reversion forecasting model can be tested for its prediction accuracy by determining (1) its success in predicting the direction of actual price change, (2) the relationship between distance from the mean and actual price change, and (3) its ability to generate significant trading profits. The first two tests are variations of market timing tests and are discussed in the next section.

Before discussing these tests, the issue of the underlying value or mean of the price needs to be addressed. In general, this value is unobserved and must be estimated, usually by a moving average of past prices. In the context of futures prices for agricultural commodities, the underlying value may reflect the cost of producing these commodities. Agricultural commodities are widely believed to be sold and bought in competitive markets. Thus, over time, prices which are higher (lower) than the cost of production will send economic signals to increase (decrease) production. Similarly, prices higher than the cost of production will discourage consumption, while a price lower than the cost of production will encourage consumption. Consequently, prices will trend toward the cost of production over time. This in turn implies that the mean price should be the cost of production. This hypothesis is tested using national average cost of production data from the U.S. Department of Agriculture.

## Tests of Forecasting Ability

### Merton Test

Following Henriksson and Merton and given the context of this study, a realized market direction variable ($A_t$) is defined as:

(3) $A_t = 1$ if $FP_{t+n} > FP_t$ (futures prices increased between times t and t+n)
(4) $A_t = 0$ if $FP_{t+n} \leq FP_t$ (futures prices decreased between times t and t+n)

where: $FP_{t+n}$ = futures price at end of trading period
$FP_t$ = futures price at beginning of trading period
$n$ = length of trading period

The probability matrix for the forecasted direction of change in futures price (binary variable $F_t$ from equations 1 and 2), conditional upon the actual direction of change in futures price (binary variable $A_t$ from equations 3 and 4), is:

(5) P1 = Prob [ $F_t = 0 \mid A_t = 0$ ]
(6) 1 - P1 = Prob [ $F_t = 1 \mid A_t = 0$ ]
(7) P2 = Prob [ $F_t = 1 \mid A_t = 1$ ]
(8) 1 - P2 = Prob [ $F_t = 0 \mid A_t = 1$ ]

where: P1 = conditional probability of a correct forecast given that price actually decreased,
1 - P1 = conditional probability of an incorrect forecast given that price actually decreased,
P2 = conditional probability of a correct forecast given that price actually increased, and
1 - P2 = conditional probability of an incorrect forecast given that price actually increased.

By assuming that the probability of correctly predicting the direction of price change does not depend upon the magnitude of the realized actual change in price, Merton (1981) shows that a forecast method would have to correctly predict the direction of price change more than 50 percent of the time if a rational investor would benefit from using the forecast (i.e., the forecast has market timing ability). Given the assumption, a success rate of greater than 50 percent will yield positive gross trading profits. Merton's test for market timing is equivalent to testing whether the sum of the conditional probabilities of P1 and P2 exceeds one.

This test can be operationalized by estimating the following regression (Breen et al.), which is presented in the context of evaluating the mean reversion forecast:

(9) $F_t = \alpha + \beta A_t + \epsilon_t$ (Merton test)

where: $F_t$ = mean reversion forecast variable defined in equations 1 and 2
$A_t$ = realized market direction variable defined in equations 3 and 4
$\alpha$ = intercept coefficient
$\beta$ = slope coefficient
$\epsilon_t$ = error term

Breen et al. show that $\beta = P1 + P2 - 1$. Therefore, if $\beta$ is significantly greater than zero the forecast method has met the sufficient condition for market timing value as defined by Merton. In the context of this study, a $\beta$ significantly greater than zero implies that the mean reversion forecasts detailed in equations 1 and 2 can predict the direction of actual market price change with an accuracy greater than 50 percent (i.e., the expected success rate of a naive buy [sell] and hold forecast if a random walk or martingale stochastic price process existed).

**Cumby-Modest Test**

In the Merton test, a buy forecast signal is generated from the mean reversion forecasts enumerated in equations 1 and 2 whether the mean price is well above or only slightly above the futures price observed at the beginning of the trading period. Cumby and Modest (1987) point out that it is reasonable to hypothesize that both the probability of price change in the forecasted direction as well as the resultant magnitude of price movement will increase as the difference between the forecasted price and current price, i.e., the trading signal, becomes larger.

To analyze the relationship between actual price change and the magnitude of the forecast signal, Cumby and Modest propose to regress the actual change in market price on the "strength" of the forecast of market direction. In a mean-reversion process, the mean price can be viewed as the forecast of price at the end of the holding period. Therefore, trading strength equals the difference between the mean price and current price. In the context of this study, the Cumby-Modest test for market timing ability of a mean reversion forecast of futures prices takes the following form:

(10) $R_t = \alpha + \beta D_t + \epsilon_t$

where:
- $R_t$ = $[(\ln FP_{t+n} - \ln FP_t) * 100]$
- $D_t$ = $[(\ln MP_t - \ln FP_t) * 100]$
- $FP_t$ = futures price at beginning of trading period
- $MP_t$ = mean price at beginning of trading period
- $FP_{t+n}$ = futures price at end of trading period
- $\ln$ = natural logarithmic operator
- $\alpha$ = intercept coefficient
- $\beta$ = slope coefficient
- $\epsilon_t$ = error term

Given the definition of the dependent and independent variable, testing for $\beta > 0$ provides statistical evidence for market timing ability in the sense that the distance from the mean is significantly related to the realized magnitude of change in prices. Stated alternatively, the more positive (negative) the difference between the mean price and the futures price at the beginning of the trading period, the greater the hypothesized increase (decrease) of the realized change in futures price.

**Implementation of Forecasting Tests for Mean-Reversion**

Futures prices for corn, soybeans, soymeal, and soyoil are from the Chicago Board of Trade. Futures prices for fed cattle, hogs, and feeder cattle are from the Chicago Mercantile Exchange. These prices were obtained via a computer database available from Technical Tools. The price series for all commodities except feeder cattle begin in January 1970. The January 1970 date was chosen due to the lack of market volume in hog futures before this date (Chicago Mercantile Exchange). The price series for feeder cattle begins in January 1972, the first full year of trading in this futures market. All price series end in June 1990, the date at which the data analysis began.

The soybean processing, cattle feeding, and hog feeding spreads are calculated as gross returns to the final outputs minus the cost of inputs traded on futures markets. These spreads, therefore, are margins offered by the futures markets to cover the costs of the unhedged inputs. Calculation of these spreads is discussed in detail in Appendix A.

To implement the market timing tests, only ex ante forecasts are used; that is, only information available at the time the forecast is made is used. Because the study of mean reversion in security prices suggests that it is a long term price process, this study tests for the market timing ability of mean reversion-based forecasts at time horizons of one, three, and six months.

The mean of the futures price or spread of the commodity is calculated as a simple moving average of previous prices. The specific prices used are the opening prices for the futures contract nearest to maturity on the first trading day of each calendar month. The first day of the month was selected to avoid erratic trading which may occur late in a delivery month.

Given that over the long run the mean price should reflect the cost of production in a competitive industry, two long-term moving averages of historical prices were used to estimate the mean: 36 and 60 months. These averages should be long enough to capture the underlying value of the commodity, i.e., its cost of production, but be short enough to reflect changes in this value. Use of both 36- and 60-month moving averages permits an evaluation of the sensitivity of the results to the length of the period used to calculate the moving average. To illustrate these calculations, the 60-month moving average for January 1980 was calculated using prices on the first trading day of the calendar month from January 1975 through December 1979. Given the use of a 60-month moving average, the mean reversion price forecasts for both the 36- and 60-month moving averages are evaluated for trades placed from January 1975 through December 1989. Because of their latter initial data point, evaluation of feeder cattle and the cattle spread begin in January 1977.

Forecast signals were generated on the first trading day of each month by comparing the estimated mean price to the closing price of the futures contract maturing nearest to, but later than, the calendar month at the end of the one-, three-, or six-month forecast horizon. The actual price change is calculated beginning with the opening price on the second trading day of the forecast period. This delay allows for the time needed to analyze the price forecast signal.

The use of overlapping forecast periods in the market timing analysis introduces potential problems of serial correlation and heteroskedasticity in the results. The regression results are adjusted for these problems according to a framework developed by Newey and West (1987).

## Results of Tests for Forecasting Ability of Mean Reversion

For the 60-month moving average estimate of mean price over the 1975-1989 sample period, the $\beta$ coefficients are significantly greater than zero at the 10 percent level of significance for all commodities and spreads at the six month trading horizon, with the exceptions of corn in the Cumby-Modest test and feeder cattle in both the Merton and Cumby-Modest tests (Tables 1 through 3). These results suggest the widespread existence of market timing ability. At three months, market timing ability at the 10 percent level of significance is found for all commodities and spreads except feeder cattle in both tests and soybeans and soyoil in the Merton test. At one month, while the Cumby-Modest test shows market timing ability of the mean reversion forecast for all commodities and spreads except feeder cattle, the Merton test shows market timing ability only for the cattle spread.

Both the level of significance and the number of $\beta$ coefficients significant at the 10 percent level are somewhat smaller when the 36-month moving average is used instead of the 60-month moving average. For example, at six months, the Cumby-Modest test shows market timing for all three spreads and all commodities except corn and feeder cattle at the 10 percent level of significance. The Merton test, however, shows market timing for only two spreads (soybean and cattle) and three commodities (soymeal, hogs, and live cattle). Nevertheless, there is significant overlap in market timing ability, suggesting that the results are substantially robust to the selection of the moving average parameter.

To test for the impact of the period of analysis on the market timing results, the sample period is divided in half: (1) forecasts initiated from January 1975 through June 1982 and (2) forecasts initiated from July 1982 through December 1989. Because of data limitations, forecasts for feeder cattle and the cattle feeding spread over the first sub-period were not initiated until January 1977.

Results are presented for the 60-month moving average. For the first sub-period, they are very similar to those for the entire sample. To illustrate, at six months, the Merton test finds that all ß coefficients are significant at the 10 percent level, except for the cattle spread. At three months, all but soybeans, feeder cattle, and the cattle spread are significant. In contrast, market timing is found at one month for only three commodities (corn, live cattle, and feeder cattle) and one spread (soybean).

During the second sub-period, the mean reversion forecast strategy does not perform well in the grains. Market timing was found in the Merton test only for corn at three months, and in the Cumby-Modest test only for soybeans at all three trading horizons and for the soybean spread at three months. In the livestock commodities, market timing is found in the Cumby-Modest test for all forecast periods in live cattle, live hogs, and the hog feeding spread, and in the cattle feeding spread at three and six months. The Merton test shows market timing at all three forecast periods for hogs, at three months for live cattle, and at three and six months for the hog spread. No evidence of market timing is found for feeder cattle and the cattle spread.

In summary, the mean reversion-based forecasts exhibit consistent market timing ability in the livestock commodities and spreads over both sub-periods. In contrast, the mean reversion-based forecasts exhibit little market timing ability for the grain commodities and spreads in the second sub-period after having exhibited substantial forecasting ability in the first period. One potential explanation for the different results for grains and livestock are the substantial changes that occurred in government price support levels over this sub-period, especially in 1986. A downward adjustment in support prices at a time when market prices were being supported by government programs would disrupt a strategy using historical prices to estimate mean prices.

## Net Trading Returns to a Mean Reversion Trading Strategy

The market timing tests suggest that mean reversion-based forecasts have ability to forecast both the direction of change and the magnitude of change in agricultural commodity futures and spread prices. Consequently, a trader might be able to exploit this forecasting ability to obtain significant trading profits. Specifically, for an individual commodity or spread, if the current price is above (below) its historical mean, a futures contract of the commodity is sold (bought). Likewise for the spreads, if the current spread is above the 60-month moving average estimate of the mean, the normal processing position (buy input, sell output) is taken. Conversely, if the current spread is below the mean, the reverse processing position (sell input, buy output) is taken. Therefore, the trades are simulated on an ex ante basis, using only information available at the time the trade is placed.

The 60-month moving average forecasts generated for the market timing tests are used to determine the trade positions. Trades are initiated for one, three, and six months in length at the opening price on the second trading day of a calendar month. The trades are placed in the futures contract maturing nearest to, but later than, the calendar month in which the trade is to be lifted. The position is offset at the opening price on the first trading day of the calendar month at the end of the trading period. Trades are made for the period beginning January 1975 and ending December 1989 except for feeder cattle and the cattle spread, which begin January 1977. Thus, the returns are generated for the period used to evaluate market timing ability.

Returns were calculated as log percentages according to:

$$(11)\quad RF_t = S_t * [(\ln FP_{t+n} - \ln FP_t) * 100]$$

where: $S_t$ = 1 if $MP_t > FP_t$ (buy signal); = -1 if $MP_t \leq FP_t$ (sell signal)
$MP_t$ = mean price at beginning of trading period
$FP_t$ = futures price at beginning of trading period
$FP_{t+n}$ = futures price at end of trading period
$\ln$ = natural logarithmic operator

These returns were adjusted for transaction costs to yield net trading returns, which were then annualized for each of the three trading horizons. To account for the overlapping forecast periods, the Newey-West adjustment is applied to the t-tests.

Transaction costs equal the sum of execution costs and brokerage fees. Execution costs are associated with having a market order filled. They reflect the size of the bid-ask spread, and increase as time from contract maturity increases and trading becomes less liquid (Brorsen and Nielsen, 1986; Thompson and Waller, 1987). Following Brorsen and Nielsen, cost of executing a futures trade is estimated at one price tick to get into each contract at trade lengths of one and three months. At the six month trade length, two ticks are used to get into each contract. The cost to close the trade is estimated at one tick per contract for all trade lengths. Based on a survey of brokers in the Columbus, Ohio area, brokerage costs for public traders are estimated at $100 per contract per round trip for an individual commodity and at $50 per contract per round trip for a contract which is part of a spread trade.

Over the 1975-1989 sample period, no significant trading returns were found at one month (Tables 4 through 6). In contrast, profits significant at 10 percent were generated for 13 of the 20 trading return series at three and six months. Only for fed and feeder cattle was no incidence of significant profits found. When the sample period was divided in half, significant net trading profits were found only for the grain complex commodities and spreads in the first half and only for hogs and the hog and cattle spread in the second half. As with the entire sample period, all significant returns occurred at the three and six month horizons. These results suggest that significant net trading profits exist for the simple mean reversion trading strategy analyzed, but that they depend on the period analyzed and exist only for the longer trade horizons.

## Moving Average and Cost of Production

It was hypothesized that the underlying value, i.e., mean price, of a commodity traded in a competitive market is its cost of production. This hypothesis is examined by comparing the 36- and 60-month moving average estimates of the mean price with the national average cost of production reported by the U.S. Department of Agriculture

(USDA) for corn, soybeans, hogs, and fed cattle. In addition, USDA's reported costs of the unhedgeable inputs used in hog and cattle feeding are compared to the historical moving average of the spreads calculated in this study.

Consistent USDA cost of production data exist back to 1975. The data is reported on a calendar year basis for crops and livestock produced during that year. The specific cost of production used in this analysis is the economic cost of production. This includes the costs of variable inputs, fixed inputs prorated to the year's production, and an opportunity cost for unpaid farm family labor.

The moving average of past prices is an estimate of the current mean value. Thus, the estimated moving average for a month is compared with USDA's cost of production for that month. Because cost of production is estimated only on a yearly basis, it follows a step function over time. To check for sensitivity, the moving average of past prices was also compared to the cost of production for the previous year. Results were similar. Results also were similar for the 36- and 60-month moving averages. Thus, only results for the 60-month moving average are reported.

The level of the 60-month moving average closely tracks both the level and direction of change in USDA cost of production data for all six commodities and spreads (Figure 2). However, a more rigorous comparison is to examine the comparability of trading signals generated by the 60-month moving average and USDA's cost of production. Therefore, a market direction forecast variable was formed for cost of production similar to that defined in equations 1 and 2 for the mean price. Thus, a price increase (decrease) was forecast whenever cost of production was greater than (less than or equal to) the futures price at the beginning of the trading period. This forecast yielded the same price direction signal as the 60-month moving average over 75 percent of the time for corn and soybeans, and over two-thirds of the time for hogs and the hog spread (Tables 7 and 8). Each commodity or spread had at least one trade length where the proportion of agreement exceeded 60 percent.

Magnitudes of the trading signals generated by these two forecasts were also compared through the following regression:

(12) $D_t = \alpha + \beta C_t + \varepsilon_t$

where: $C_t$ = [ $(\ln CP_t - \ln FP_t) * 100$ ]
$CP_t$ = USDA cost of production at beginning of trading period
$D_t$, $FP_t$, $\alpha$, $\beta$, and $\varepsilon_t$ are defined as in equation 10

If the trading signals are equivalent, $\alpha$ would equal zero and $\beta$ would equal one. The Newey-West procedure is used to correct for the overlapping sample problem.

Excluding the cattle spread, the $R^2$ for all regressions exceeded 0.24 (Tables 7 and 8). This implies a correlation of roughly 0.5 or higher between the magnitude of the trading signals generated by USDA's cost of production and the 60-month moving average. Furthermore, only for the cattle spread does the $\beta$ differ materially from one, although statistically significant differences also occur for corn and hogs at one month and for the hog spread at one and three months. In contrast, the $\alpha$'s, and therefore the Chi-square test of the joint hypothesis [$\alpha = 0; \beta = 1$], are almost always significantly different from zero. This is not surprising, given that the costs of production are national averages while the futures contracts become spot contracts at (a) delivery market(s). Thus, the $\alpha$'s probably capture the basis difference between the two series.

In summary, there appears to be strong support in general for the hypothesis that the underlying value of the agricultural commodities and spreads examined is the cost of production. Of particular significance was the finding that, in general, changes in the deviations of current prices from the 60-month moving average of prices approximately equal changes in the deviations of current prices from USDA's cost of production.

## Conclusions and Implications

Results of the market timing tests and returns to the simulated trading strategy are consistent with the presence of mean reversion in the agricultural commodities and processing spreads included in this study, with the exception of feeder cattle. The evidence is much stronger at the three and six month horizons than at the one month horizon. This distinction is consistent with the studies of mean reversion in security prices, which have found evidence of mean reversion only at longer time horizons. This study is not inconsistent with the majority of studies that find a random walk or martingale in futures price changes over a daily or weekly time intervals, but it does suggest that random walk or martingale price processes may not be appropriate at time horizons longer than one month.

This study provides evidence that the underlying value, i.e., mean, of these agricultural futures prices is the cost of production. Deviations from the mean price would therefore bring about economic supply and demand responses which, in turn, would result in a mean reversion price process. A reasonable extension of this argument is that one reason futures prices may deviate from their mean value is to signal appropriate economic responses on the part of producers and consumers. This, in turn, implies that over longer periods futures prices are not unbiased predictors of subsequent futures prices because economic responses modify the original forecasts.

Stein (1981) provided theoretical evidence that the optimality of resource allocation depends on the accuracy of futures price forecasts of subsequent realized prices. Results of this study suggest that futures prices of the analyzed agricultural commodities and spreads are not unbiased forecasts over longer time periods. Therefore, according to Stein's theoretical model, the futures prices and spreads are not producing an optimal allocation of resources. However, the results of this study are consistent with the economic response of producers and consumers to incentives or disincentives and, therefore, with Cootner's (1964) and Samuelson's (1976) observation that prices are not truly a random walk but are constrained by economically determined barriers.

This research also provides a foundation of support for the findings of the profit margin hedging studies. These studies have found that selective implementation of a profit margin trading rule increased mean return and/or reduced the standard deviation of returns compared to a cash only or routine hedging strategy (for examples, see Kenyon and Shapiro, 1976; Spahr and Sawaya, 1981; and Schroeder and Hayenga, 1988). A profit margin trading rule initiates trades when a pre-specified level of implied profit exists. Implied profit is derived from currently-quoted futures prices for the output of the production process and estimated production costs. The existence of profit margin trading signals are consistent with a mean reversion process, where the mean is the cost of production. Profit margin hedging studies, therefore, deserve more analysis.

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## Appendix A: Calculation of Spreads

The processing margin for soybeans in dollars per bushel of soybeans at time t for time t+n ($SOYPM_{t,\,t+n}$) is calculated as:

$$(1)\quad SOYPM_{t,t+n} = [(12*(PSM_{t,t+n}*48)/2000 \text{ lbs.}) + (9*(PSO_{t,t+n}*11)/100 \text{ lbs.})-10*PSB_{t,t+n}]$$

where: $PSM_{t,t+n}$ = price of soymeal in dollars per ton at time t for time t+n
$PSO_{t,t+n}$ = price of soyoil in dollars per cwt at time t for time t+n
$PSB_{t,t+n}$ = price of soybeans in dollars per bushel at time t for time t+n
t = beginning of trading period
t+n = end of trading period
n = length of trading period

This calculation utilizes the long-term average yield of 48 pounds of meal and 11 pounds of oil from a bushel (60 pounds) of soybeans (U.S. Department of Agriculture [USDA], 1988). The different sizes of soymeal, soyoil, and soybean futures contracts, along with the specified yield, require that 12 soymeal, 9 soyoil, and 10 soybean contracts be traded.

The feeding margin for cattle in dollars per hundredweight (cwt) of fed cattle at time t for time t+n ($LCPM_{t,\,t+n}$) is calculated as:

$$(2)\quad LCPM_{t,t+n} = [7*PLC_{t,t+n} - ((4*PFC_{t,t+n}*\ 60 \text{ lbs.}) + (PCO_{t,t+n}*\ 4.6 \text{ bu.}))]$$

where: $PLC_{t,t+n}$ = price of fed cattle in dollars per cwt at time t for time t+n
$PFC_{t,t+n}$ = price of feeder cattle in dollars per cwt at time t for time t+n
$PCO_{t,t+n}$ = price of corn in dollars per bushel at time t for time t+n

This calculation assumes that 100 pounds of fed cattle are produced by feeding 4.6 bushels of corn for every 60 pounds of feeder cattle. These values are taken from USDA's national cost of production surveys (1989 and 1990). The different sizes of fed cattle, feeder cattle, and corn futures contracts, along with the specified feed conversion ratios, require that 7 fed cattle, 4 feeder cattle, and 1 corn contract be traded.

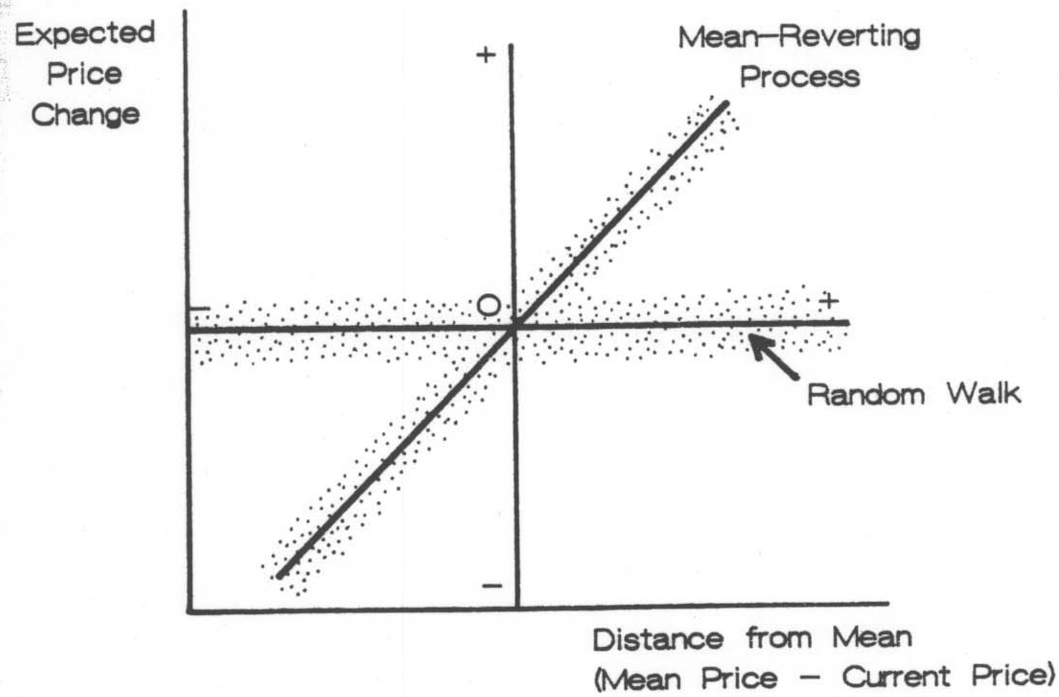
The feeding margin for hogs in dollars per cwt at time t for time t+n ($LHPM_{t,\,t+n}$) is calculated as:

$$(3)\quad LHPM_{t,\,t+n} = [(9*PLH_{t,\,t+n}) - ((3*PCO_{t,\,t+n}*6.38 \text{ bu.}) + (PSM_{t,\,t+n}*0.038 \text{ tons}))]$$

where: $PLH_{t,t+n}$ = price of hogs in dollars per cwt at time t for time t+n
$PCO_{t,t+n}$ = price of corn in dollars per bushel at time t for time t+n
$PSM_{t,t+n}$ = price of soymeal in dollars per ton at time t for time t+n

This calculation assumes an average consumption of 6.38 bushels of corn and 0.038 tons (76 pounds) of soymeal per hundred pounds of market hog produced. These values are taken from USDA's national cost of production surveys (1989 and 1990). The different sizes of hog, corn, and soymeal futures contracts, along with the specified conversion ratios, require that 9 hog, 3 corn, and 1 soymeal contract be traded.

Figure 1. Stylized Comparison of Random Walk and Mean Reversion Price Process.



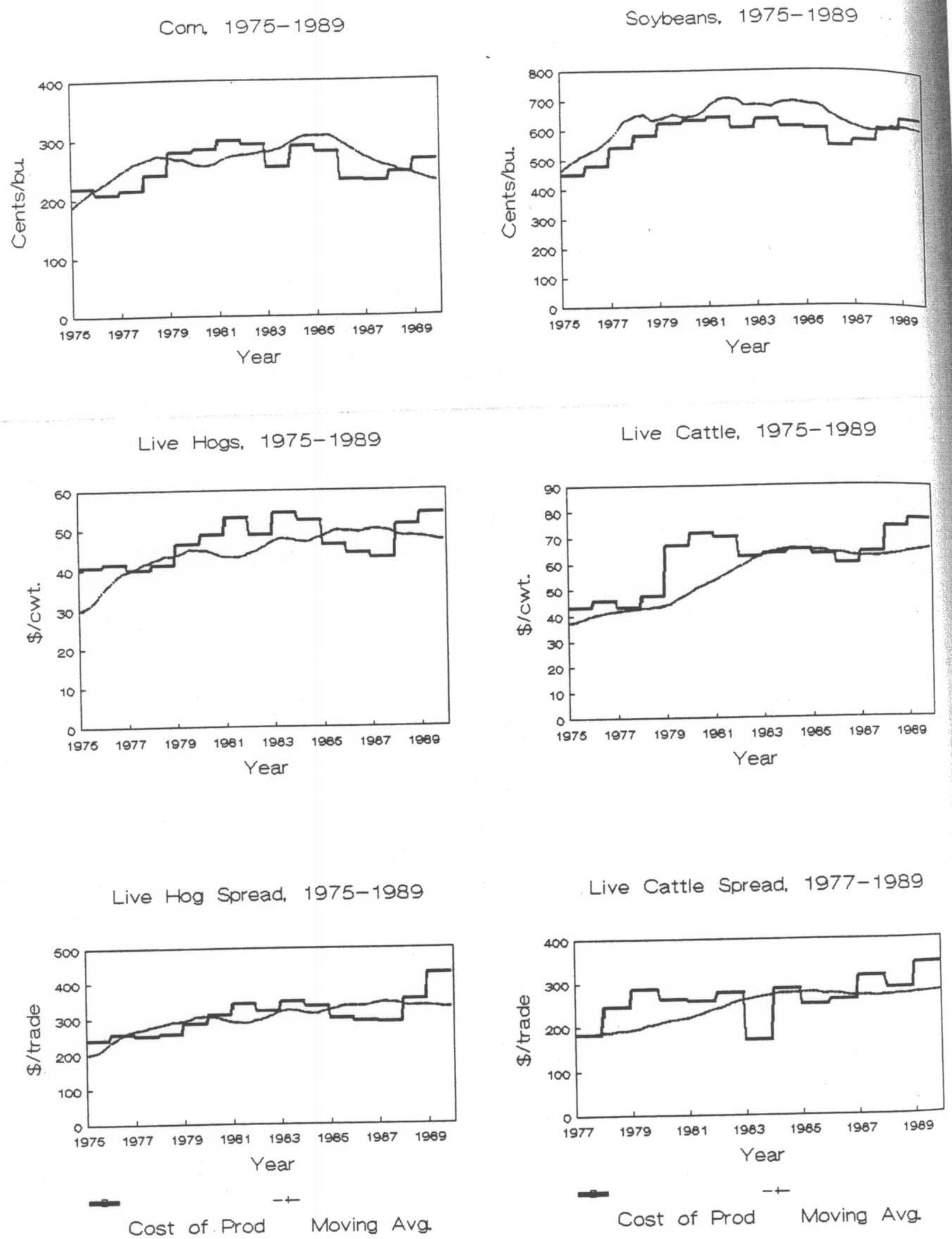



**Figure 2. 60-month Moving Average vs. Cost of Production**
**SOURCE: Chicago Board of Trade, Chicago Mercantile Exchange, United States Department of Agriculture.**

**Table 1. Market Timing Tests for 60-Month and 36-Month Moving Averages. Corn, Soybean, Soymeal, and Soyoil, 1975-1989.**

| Commodity | Trading Horizon | 60-Month Moving Average 1975-1989[a] | | 60-Month Moving Average 1975:1-1982:6[a] | | 60-Month Moving Average 1982:7-1989:12[a] | | 36-Month Moving Average 1975-1989[a] | |
|---|---|---|---|---|---|---|---|---|---|
| | | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ |
| Corn | 1 mo. | 0.09 (1.24) | 0.05 (2.08)** | 0.13 (1.32)* | 0.05 (1.43)* | 0.05 (0.48) | 0.04 (1.14) | 0.07 (0.90) | 0.04 (1.45)* |
| | 3 mo. | 0.23 (2.37)*** | 0.10 (1.88)** | 0.18 (1.40)* | 0.12 (1.75)*** | 0.18 (1.62)* | 0.07 (1.00) | 0.05 (0.56) | 0.07 (1.22) |
| | 6 mo. | 0.25 (1.70)** | 0.15 (1.28) | 0.33 (1.71)** | 0.23 (1.97)** | 0.15 (0.81) | 0.05 (0.28) | 0.03 (0.25) | 0.08 (0.74) |
| Soybean | 1 mo. | 0.02 (0.29) | 0.10 (3.23)*** | 0.05 (0.54) | 0.17 (2.98)*** | 0.06 (0.54) | 0.06 (1.69)** | 0.05 (0.61) | 0.07 (2.33)*** |
| | 3 mo. | 0.12 (1.11) | 0.25 (2.86)*** | 0.17 (1.18) | 0.47 (2.89)*** | 0.07 (0.45) | 0.16 (2.03)** | 0.04 (0.42) | 0.20 (2.13)** |
| | 6 mo. | 0.27 (1.86)** | 0.38 (3.08)*** | 0.36 (1.88)** | 0.70 (3.52)*** | 0.23 (1.19) | 0.26 (2.26)** | 0.17 (1.20) | 0.32 (2.44)*** |
| Soymeal | 1 mo. | 0.01 (0.15) | 0.05 (1.71)** | 0.07 (0.64) | 0.14 (2.37)** | -0.01 (-0.06) | 0.00 (0.03) | 0.01 (0.15) | 0.03 (1.17) |
| | 3 mo. | 0.25 (2.38)*** | 0.18 (1.62)* | 0.32 (2.62)*** | 0.45 (2.43)*** | 0.19 (1.15) | 0.05 (0.49) | 0.15 (1.29)* | 0.14 (1.20) |
| | 6 mo. | 0.25 (2.03)*** | 0.25 (1.68)** | 0.25 (1.78)** | 0.62 (3.55)*** | 0.23 (1.13) | 0.11 (0.61) | 0.17 (1.37)* | 0.21 (1.29)* |
| Soyoil | 1 mo. | 0.01 (0.14) | 0.07 (2.36)*** | 0.03 (0.29) | 0.16 (2.90)*** | -0.01 (-0.10) | 0.02 (0.59) | -0.06 (-0.85) | 0.03 (1.28)* |
| | 3 mo. | 0.11 (0.96) | 0.23 (2.79)*** | 0.23 (1.45)* | 0.41 (3.19)*** | -0.03 (-0.23) | 0.12 (1.16) | 0.00 (0.00) | 0.12 (1.76)** |
| | 6 mo. | 0.30 (2.15)** | 0.42 (2.58)*** | 0.38 (2.13)** | 0.71 (3.07)*** | 0.22 (1.07) | 0.24 (1.27) | 0.04 (0.30) | 0.21 (1.70)** |

a/ T-ratios reported in parentheses.
b/ One-tailed t-test for significance.

* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Board of Trade, Original Calculations.**

**Table 2. Market Timing Tests for 60-Month and 36-Month Moving Averages. Hogs and Cattle, 1975-1989; Feeder Cattle, 1977-1989.**

| | | 60-Month Moving Average 1975-1989 | | 60-Month Moving Average 1975:1-1982:6[a] | | 60-Month Moving Average 1982:7-1989:12[a] | | 36-Month Moving Average 1975-1989 | |
|---|---|---|---|---|---|---|---|---|---|
| Commodity | Trading Horizon | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^c$ | Cumby-Modest $\beta^b$ |
| Hogs | 1 mo. | 0.11 (1.41) | 0.09 (2.71)*** | 0.04 (0.34) | 0.08 (1.94)** | 0.20 (1.95)** | 0.13 (2.48)*** | 0.12 (1.63) | 0.11 (3.04)*** |
| | 3 mo. | 0.29 (3.07)*** | 0.23 (2.15)** | 0.22 (1.61)* | 0.20 (1.60)* | 0.40 (3.45)*** | 0.48 (3.79)*** | 0.25 (2.67)*** | 0.31 (3.13)*** |
| | 6 mo. | 0.29 (2.91)*** | 0.45 (2.43)*** | 0.27 (1.87)** | 0.43 (1.90)** | 0.38 (3.61)*** | 0.69 (5.24)*** | 0.19 (1.87)** | 0.48 (3.14)*** |
| Fed Cattle | 1 mo. | 0.07 (0.90) | 0.06 (2.11)** | 0.13 (1.40)* | 0.08 (1.61)* | -0.05 (-0.42) | 0.07 (1.33)* | 0.03 (0.43) | 0.06 (1.72) |
| | 3 mo. | 0.24 (2.72)*** | 0.19 (2.52)*** | 0.19 (1.88)** | 0.24 (2.16)** | 0.20 (1.45)* | 0.28 (2.56)*** | 0.16 (1.72)** | 0.19 (1.95)** |
| | 6 mo. | 0.24 (2.16)** | 0.21 (2.02)** | 0.18 (1.57)* | 0.27 (1.59)* | 0.12 (0.63) | 0.27 (1.66)** | 0.18 (1.62)* | 0.18 (1.37)* |
| Feeder Cattle[c] | 1 mo. | 0.08 (1.03) | 0.02 (0.79) | 0.19 (2.21)** | 0.02 (0.65) | -0.05 (-0.42) | 0.02 (0.45) | 0.02 (0.23) | 0.01 (0.41) |
| | 3 mo. | 0.05 (0.48) | 0.07 (0.94) | 0.17 (1.13) | 0.11 (1.21) | -0.02 (-0.17) | 0.07 (0.68) | -0.01 (-0.13) | 0.01 (0.15) |
| | 6 mo. | 0.15 (1.28) | 0.11 (1.01) | 0.18 (1.36)* | 0.19 (1.28) | 0.06 (0.36) | 0.05 (0.47) | 0.08 (0.65) | -0.02 (-0.12) |

a/ T-ratios reported in parentheses.
b/ One-tailed t-test for significance.
c/ Sample periods for feeder cattle are 1977 through 1989 for the entire period and January 1977 through June 1982 for the first sub-period.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Mercantile Exchange, Original Calculations.**

**Table 3. Market Timing Tests for 60-Month and 36-Month Moving Averages. Soybean Spread, Hog Spread, 1975-1989, and Cattle Spread, 1977-1989[a]**

| | | 60-Month Moving Average 1975-1989[a] | | 60-Month Moving Average 1975:1-1982:6[a] | | 60-Month Moving Average 1982:7-1989:12[a] | | 36-Month Moving Average 1975-1989[a] | |
|---|---|---|---|---|---|---|---|---|---|
| | Trading Horizon | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ | Merton $\beta^b$ | Cumby-Modest $\beta^b$ |
| Soybean Spread | 1 mo. | 0.04 (0.60) | 0.08 (1.61)* | 0.16 (1.48)* | 0.16 (1.85)** | -0.07 (-0.67) | 0.03 (0.47) | 0.07 (0.89) | 0.10 (2.03)** |
| | 3 mo. | 0.23 (2.36)*** | 0.39 (2.93)*** | 0.32 (2.49)*** | 0.51 (3.00)*** | 0.12 (0.89) | 0.23 (1.76)** | 0.17 (1.65)** | 0.39 (2.97)*** |
| | 6 mo. | 0.28 (2.49)*** | 0.48 (2.75)*** | 0.39 (2.49)*** | 0.67 (3.63)*** | 0.16 (1.05) | 0.19 (0.86) | 0.29 (2.35)*** | 0.48 (3.14)*** |
| Hog Spread | 1 mo. | 0.05 (0.66) | 0.08 (2.48)*** | 0.03 (0.25) | 0.08 (1.77)** | 0.09 (0.84) | 0.11 (2.16)** | 0.01 (0.17) | 0.09 (2.56)*** |
| | 3 mo. | 0.27 (2.97)*** | 0.23 (2.18)** | 0.26 (1.95)** | 0.19 (1.60)* | 0.31 (2.96)*** | 0.42 (3.45)*** | 0.24 (2.62)*** | 0.25 (2.73)*** |
| | 6 mo. | 0.26 (2.18)** | 0.37 (2.05)** | 0.27 (1.72)** | 0.34 (1.64)* | 0.30 (2.44)*** | 0.60 (4.70)*** | 0.13 (1.17) | 0.42 (2.63)*** |
| Cattle Spread[c] | 1 mo. | 0.12 (1.61)* | 0.09 (2.34)*** | 0.06 (0.60) | 0.15 (2.32)** | 0.11 (1.04) | 0.09 (1.18) | 0.07 (0.91) | 0.08 (1.79)** |
| | 3 mo. | 0.17 (1.73)** | 0.28 (3.88)*** | 0.17 (1.40) | 0.40 (3.72)*** | 0.09 (0.71) | 0.40 (3.22)*** | 0.25 (2.47)*** | 0.28 (3.01)*** |
| | 6 mo. | 0.21 (1.92)** | 0.28 (3.15)*** | 0.21 (1.28) | 0.45 (3.22)*** | 0.12 (0.73) | 0.40 (2.12)*** | 0.14 (1.34)* | 0.27 (2.26)** |

a/ T-ratios reported in parentheses.
b/ One-tailed test for significance.
c/ Sample periods for the cattle spread are 1977 through 1989 for the entire period and January 1977 through June 1982 for the first sub-period.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level

**SOURCE: Chicago Board of Trade, Chicago Mercantile Exchange, Original Calculations.**

**Table 4. Mean Annualized Percentage Returns in Excess of Transaction Costs for Mean Reversion Trading Strategy. 60-Month Moving Average. Corn, Soybeans, Soymeal, and Soyoil, 1975-1989[a,b].**

| | | Returns to Trading Strategy by Sample Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1975:1-1989:12 | | 1975:1-1982:6 | | 1982:7-1989:12 | |
| Commodity | Trading Horizon | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Percent Mean Annual Return |
| Corn | 1 mo. | 46 | -2.76 (-0.44) | 47 | -2.04 (-0.26) | 44 | -3.36 (-0.35) |
| | 3 mo. | 57 | 3.76 (0.70) | 57 | 4.32 (0.61) | 53 | 3.16 (0.40) |
| | 6 mo. | 59 | 6.72 (1.35)* | 59 | 11.34 (1.76)** | 49 | 2.12 (0.29) |
| Soybean | 1 mo. | 49 | 4.68 (0.69) | 51 | 9.72 (0.91) | 47 | -0.48 (-0.05) |
| | 3 mo. | 55 | 12.04 (1.97)** | 60 | 19.60 (2.14)** | 50 | 4.44 (0.59) |
| | 6 mo. | 62 | 8.76 (1.86)** | 69 | 12.38 (1.87)** | 56 | 5.16 (0.84) |
| Soymeal | 1 mo. | 45 | 0.96 (0.13) | 47 | 13.08 (1.15) | 43 | -11.16 (-1.30) |
| | 3 mo. | 61 | 9.44 (1.40)* | 66 | 18.16 (1.92)** | 56 | 0.72 (0.08) |
| | 6 mo. | 62 | 2.74 (0.51) | 64 | 5.76 (0.90) | 59 | -0.28 (-0.03) |
| Soyoil | 1 mo. | 47 | -5.52 (-0.68) | 48 | 3.12 (0.26) | 46 | -14.04 (-1.32) |
| | 3 mo. | 52 | 10.80 (1.65)** | 60 | 18.68 (2.17)** | 43 | 2.92 (0.31) |
| | 6 mo. | 63 | 12.00 (2.01)** | 67 | 15.10 (2.23)** | 60 | 8.90 (0.95) |

[a]/ T-ratios reported in parentheses.
[b]/ One-tailed test for significance.

* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Board of Trade, Original Calculations.**

**Table 5. Mean Annualized Percentage Returns in Excess of Transaction Costs for Mean Reversion Trading Strategies. 60-Month Moving Average. Live Hogs and Live Cattle, 1975-1989; Feeder Cattle, 1977-1989[a,b].**

| | | Returns to Trading Strategy by Sample Period | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1975:1-1989:12 | | 1975:1-1982:6 | | 1982:7-1989:12 | |
| Commodity | Trading Horizon | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Percent Mean Annual Return |
| Hogs | 1 mo. | 53 | 6.60 (0.99) | 48 | 6.12 (0.57) | 58 | 7.08 (0.89) |
| | 3 mo. | 62 | 11.76 (2.06)** | 58 | 7.56 (0.81) | 66 | 16.00 (2.51)*** |
| | 6 mo. | 63 | 8.66 (2.08)** | 61 | 8.50 (1.15) | 64 | 8.84 (2.40)*** |
| Fed Cattle | 1 mo. | 45 | -5.20 (-0.96) | 49 | -3.72 (-0.41) | 41 | -6.48 (-1.20) |
| | 3 mo. | 57 | 4.44 (1.18) | 58 | 3.92 (0.64) | 57 | 5.00 (1.15) |
| | 6 mo. | 57 | 3.08 (1.08) | 60 | 3.26 (0.72) | 54 | 2.90 (0.84) |
| Feeder Cattle[c] | 1 mo. | 47 | -3.36 (-0.72) | 53 | -1.20 (-0.14) | 42 | -5.06 (-1.00) |
| | 3 mo. | 50 | -0.04 (-0.01) | 55 | 2.44 (0.30) | 47 | -1.88 (-0.45) |
| | 6 mo. | 55 | 2.76 (0.80) | 61 | 3.52 (0.51) | 50 | 2.20 (0.68) |

a/ T-ratios reported in parentheses.
b/ One-tailed test for significance.
c/ Sample periods for feeder cattle are 1977 through 1989 for the entire period and January 1977 through June 1982 for the first sub-period.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Mercantile Exchange, Original Calculations.**

**Table 6. Mean Annualized Percentage Returns in Excess of Transaction Costs for Mean Reversion Trading Strategies. 60-Month Moving Average. Soybean Spread and Live Hog Spread, 1975-1989; Live Cattle Spread, 1977-1989[a,b].**

| | | Returns to Trading Strategy by Sample Period (60-month Moving Average) | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1975:1-1989:12 | | 1975:1-1982:6 | | 1982:7-1989:12 | |
| Spread | Trading Horizon | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Percent Mean Annual Return | Percent Profitable Trades | Mean Annual Return |
| Soybean Spread | 1 mo. | 51 | 4.68 (0.33) | 57 | 26.52 (1.13) | 46 | -17.04 (-1.00) |
| | 3 mo. | 59 | 20.40 (1.90)** | 66 | 29.16 (1.91)** | 53 | 11.64 (0.79) |
| | 6 mo. | 62 | 11.80 (1.74)** | 68 | 19.20 (2.21)** | 56 | 4.40 (0.45) |
| Hog Spread | 1 mo. | 52 | 6.24 (0.79) | 49 | 7.44 (0.59) | 54 | 5.16 (0.53) |
| | 3 mo. | 62 | 16.92 (2.59)*** | 60 | 13.32 (1.20) | 63 | 20.56 (3.01)*** |
| | 6 mo. | 61 | 10.08 (1.95)** | 60 | 8.96 (0.98) | 61 | 11.20 (2.36)*** |
| Cattle Spread[c] | 1 mo. | 51 | 1.68 (0.26) | 49 | -2.76 (-0.23) | 52 | 4.92 (0.72) |
| | 3 mo. | 55 | 3.56 (0.78) | 55 | 0.04 (0.00) | 56 | 6.16 (1.27) |
| | 6 mo. | 56 | 4.96 (1.50)* | 53 | 2.38 (0.40) | 58 | 6.84 (1.95)** |

a/ T-ratios reported in parentheses.
b/ One-tailed test for significance.
c/ Sample periods for the cattle spread are 1977 through 1989 for the entire period and January 1977 through June 1982 for the first sub-period.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Board of Trade, Chicago Mercantile Exchange, Original Calculations.**

**Table 7. Relationship between Trading Signals from 60-Month Moving Average and U.S. Department of Agriculture Cost of Production. Corn, Soybeans, Live Hogs, and Live Cattle, 1975-1989.[a]**

| | | | Regression of Trading Signals from 60-Month Moving Average on Trading Signal from USDA Cost of Production | | | |
|---|---|---|---|---|---|---|
| Commodity | Trading Horizon | Percent Same Signal | $\alpha^b$ | $\beta^c$ | $R^2$ | Chi-square[d] |
| Corn | 1 mo. | 79 | 3.32 (4.19)*** | 1.10 (2.46)** | 0.787 | 21.96*** |
| | 3 mo. | 80 | 3.48 (2.04)** | 1.12 (1.38) | 0.783 | 5.43* |
| | 6 mo. | 81 | 3.75 (1.57) | 1.14 (1.17) | 0.772 | 3.26 |
| Soybeans | 1 mo. | 83 | 8.32 (16.58)*** | 1.04 (1.64) | 0.897 | 358.22*** |
| | 3 mo. | 80 | 8.44 (7.71)*** | 1.05 (0.98) | 0.894 | 78.90*** |
| | 6 mo. | 77 | 8.64 (5.59)*** | 1.06 (0.98) | 0.881 | 40.91*** |
| Hogs | 1 mo. | 76 | -5.11 (-6.07)*** | 0.85 (-2.92)*** | 0.630 | 90.12*** |
| | 3 mo. | 77 | -5.07 (-2.63)*** | 0.90 (-1.00) | 0.592 | 19.35*** |
| | 6 mo. | 72 | -3.46 (-1.38) | 0.87 (-1.06) | 0.537 | 5.88** |
| Fed Cattle | 1 mo. | 61 | -10.56 (-10.43)*** | 0.93 (-0.61) | 0.244 | 137.07*** |
| | 3 mo. | 59 | -11.03 (-4.82)*** | 1.07 (0.35) | 0.271 | 28.78*** |
| | 6 mo. | 54 | -11.34 (-3.59)*** | 1.11 (0.53) | 0.285 | 14.44*** |

a/ T-ratios reported in parentheses.
b/ Test of hypothesis $\alpha = 0$.
c/ Test of hypothesis $\beta = 1$.
d/ Test of joint hypothesis, $\alpha = 0, \beta = 1$.

* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Board of Trade, Chicago Mercantile Exchange, U.S. Department of Agriculture, Original Calculations.**

**Table 8. Relationship between Trading Signals from 60-Month Moving Average and U.S. Department of Agriculture Cost of Production. Live Hog Spread, 1975-1989 and Live Cattle Spread, 1977-1989.**

| | | | Regression of Trading Signals from 60-Month Moving Average on Trading Signal from USDA Cost of Production | | | |
|---|---|---|---|---|---|---|
| Spread | Trading Horizon | Percent Same Signal | $\alpha^b$ | $\beta^c$ | $R^2$ | Chi-square[d] |
| Hog Spread | 1 mo. | 81 | 2.03 (2.50)** | 0.77 (-5.56)*** | 0.716 | 35.00*** |
| | 3 mo. | 71 | -9.00 (-3.99)*** | 0.78 (-2.36)** | 0.658 | 52.40*** |
| | 6 mo. | 68 | -9.63 (-2.85)*** | 0.80 (-1.31) | 0.597 | 24.91*** |
| Cattle Spread | 1 mo. | 61 | 6.66 (6.20)*** | 0.15 (-13.12)*** | 0.032 | 255.12*** |
| | 3 mo. | 72 | 6.01 (2.52)** | 0.17 (-5.78)*** | 0.145 | 50.98*** |
| | 6 mo. | 55 | 6.38 (1.83)* | 0.16 (-4.17)*** | 0.034 | 27.07*** |

[a]/ T-ratios reported in parentheses.
[b]/ Test of hypothesis $\alpha = 0$.
[c]/ Test of hypothesis $\beta = 1$.
[d]/ Test of joint hypothesis $\alpha = 0$, $\beta = 1$.
* Denotes significance at the 10% level.
** Denotes significance at the 5% level.
*** Denotes significance at the 1% level.

**SOURCE: Chicago Board of Trade, Chicago Mercantile Exchange, USDA, Original Calculations.**