Information Content of Volatilities Implied by Option Premiums in Grain Futures Markets

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INTRODUCTION

Many new opportunities have become available for market participants since the inception of trading options on selected agricultural futures contracts. Critical to the use of options to many traders is some type of option pricing model; the most common is the option valuation formula developed by Black (1976). The solution to this formula results in an estimate of the fair market value of the option premium which is functionally related to interest rate, time-to-maturity of the option, futures and exercise price, and standard deviation of the futures' price returns over the remaining life of the option. Of those inputs to the Black model, the standard deviation of futures price returns is the only parameter to be estimated. The other parameters are easily observable.[1] The model was originally developed assuming a constant variance in the stochastic process. Thus, a measure of historical standard deviation of futures returns could reasonably be used in the model. However, a number of studies have demonstrated the nonconstancy of the variance of futures returns, especially in agricultural futures contracts (see Anderson (1985), Hauser and Andersen (1987), Kenyon, Kling, Jordan, Scale, and McCabe (1987)). Consequently, in practical use of option valuation models, traders must use estimates of futures volatility, which systematically reflect scheduled informational events (see Patell and Wolfson (1982)).

The standard deviation which is implied in an option premium reflects expectations of the volatility of returns over the remaining life of the contract and can be obtained by equating the observed option premium and other model input parameters using an iterative solution technique. This approach is appropriate if the observed option premium has captured or summarized all relevant information. If the Black model is accurate and if the market is efficient, this computed implied standard deviation (ISD) captures all relevant information regarding the expected standard deviation of the futures returns over the remaining life of the option. As a result, no other variable should yield significant

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[1]Although the interest rate needs to be forecast, the study by Plato (1985) and others have shown that the interest rate forecast has little impact on the option premium. Therefore, the observed Treasury Bill interest rate is used as the parameter in this study.

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information for this expected standard deviation over and above that explained by the ISD. Thus, following Heaton (1986), the ISD should be a "sufficient statistic" of the predicted futures price volatility over the remaining life of the option. That is, forecasts of volatility using ISD alone should be superior and other information should not systematically improve the ISD forecasts of volatility.

In this article the informational efficiency of an option market is judged through comparisons of the market's variance forecast (proxied by the implied volatility) with realized volatilities (see Latane and Rendleman (1976)).[2] The concept that the ISD derived from option pricing should reflect *ex ante* futures price variability[3] is intuitive given an efficient market. If the commodity options are priced properly, historical information as well as *ex ante* information (such as volatility of the futures price over the remaining life of the contract) should be summarized in the current option price. Therefore, the ISD, which is then derived from its current price (assumed properly priced), should sufficiently capture the standard deviation of futures prices over the remaining life of the contract.

The purpose of this article is to test the information content of the implied standard deviation in selected agricultural options markets. A methodology is proposed to analyze the predictive capability in the agricultural options markets. The results are important to traders and other market participants who regularly use estimates of volatility in option valuation models. The results reveal that the options markets on grain futures as opposed to stock option markets, performed poorly in anticipating volatility of the underlying futures markets using the Black option model.

PREVIOUS STUDIES

Since the suggestion of the potential benefits of options for farm markets (see Gardner (1987)), the ability to use these markets as a source of information has become an important area of research. Several studies on agricultural futures prices have demonstrated and analyzed the nonconstancy of variance. Anderson (1985) introduced the state-variable concept and showed that seasonal effects are of greater importance than the maturity effect. Subsequently, Hauser and Neff (1985), Hauser and Andersen (1987), and Kenyon, Kling, Jordan, Seale, and McCabe (1987) each analyzed the relationship between futures price volatility and fundamental economic phenomenon. Wilson, Fung, and Ricks (1988) recently analyzed selected agricultural option premiums and made comparisons to those estimated from the Black pricing model. Results indicated that significant differences existed between individual premiums and those estimated from the Black model. These differences were functionally related to time-to-maturity and standard deviation. This relationship was consistent with the literature and was due to inherent differences between American and European options (see Merton (1973)). In addition, actual premiums were found not to move on a one-to-one basis with Black premiums.

There have been numerous studies on the stock options market. Only those directly related to the methodology used in this study are reviewed here. Latane and Rendleman (1976) introduced the literature that suggested ISDs reflected in option premiums should be anticipatory of future volatility. Their analysis tested the ability of investors to make good estimates of return variability from common stocks. The results indicted that the

[2]The study by Hauser and Neff (1985) argues that such judgment should be coined "accuracy studies" as opposed to "efficiency studies." However, since the test of market efficiency is a joint test, use of the term "efficiency" should encompass "accuracy."

[3]*Ex ante* futures price variability is used here and throughout the text as the variability expected to exist in futures prices from time t to maturity.

highest correlation with ISD was obtained by using future standard deviation of returns. In other words, the ISDs had a higher correlation with the *ex ante* than the *ex post* standard deviation. Thus, the ISDs were a better predictor of future volatility than the standard deviation based on historical data.

Beckers extended the methodology in several dimensions as applied to stocks. Regressions were estimated using the actual volatility of the daily stock price returns as the dependent variable and ISDs, with alternative weighting schemes, as independent variables. Results indicated that current option prices did not reflect all available information. Consequently, option market efficiency was questioned. In addition, Beckers (1981) demonstrated that the most relevant information was reflected in at-the-money options.

More recently, Heaton (1986) conducted similar analyses using a longer time period and demonstrated methodological problems in previous studies. In particular, if the regressions suffer from autocorrelation and/or instability of coefficients, alternative test procedures are needed. Heaton's results confirmed previous work indicating that ISD is a sufficient statistic (inclusion of historical volatility did not improve ISD forecasts of actual volatility).

EMPIRICAL PROCEDURES

In this study the information content of ISDs on selected agricultural options markets is analyzed. In particular, tests are conducted regarding the ability of the options market to anticipate futures volatility, assuming that anticipation is being reflected in the ISDs. The widely known Black model is the basis of analysis and can be expressed as:

$$c_t = [P_f N(d_1) - XN(\mathrm{d}_2)]e^{-r(T-t)}$$

where

$$d_1 = \frac{\ln(P_f/X) + (\sigma^2/2)(T-t)}{\sigma\sqrt{T-t}} \tag{1}$$

$$d_2 = d_1 - \sigma\sqrt{T-t}$$

c is the call premium; P_f is the underlying futures price; X is the strike price; r is the constant riskless interest rate; T is maturity and $T - t$ is time-to-maturity; σ^2 is the variance of the futures prices; and $N(\ )$ is the cumulative normal density function. Variance in the option pricing model should be the anticipated variance over the remaining life of the option. Thus, it is not observable and must be estimated by market participants.

Black (1976) derived the model by assuming a constant variance rate in the diffusion process. In the commodity futures market, variance has been shown to be not constant due to maturity, seasonal effects, and option market fundamentals (see Samuelson (1965), Anderson (1985), Milonas, (1986), Hauser and Andersen (1987), and Kenyon, Kling, Jordan, Seale, and McCabe (1987). However, variance of the futures price can be allowed to change as a function of time (see Merton (1973), Kolb and Gay (1985)). The definition of σ^2 is then formulated as:

$$\sigma^2(T-t) = \left[\int_0^{T-t} \sigma^2(t)dt\right] / (T-t)$$

Given an efficient market, the ISD obtained from the Black model should capture and summarize the *ex ante* nonstable property of the underlying variance rate. Using observed option premiums and solving for σ^2 in eq. (1) results in an ISD that reflects the expected σ^2 as reflected in the option premium.[4] Thus, the extent to which the ISD reflects information regarding the realized volatilities is being tested.

The validity of the tests used in this study is based on the efficient market hypothesis that assumes that the model used for testing is correct and that the current option price has correctly summarized all relevant information, both historical and anticipatory. Thus, the test is a joint test of hypotheses as Fama (1976) argued. Only if the Black model is assumed valid can statements be made about market efficiency.[5] If the Black model is accurate, the ISDs should reflect anticipated volatility including informational events.

Important informational events prior to expiration of the option should be anticipated by market participants as reflected in premiums and therefore in the ISDs. Consequently, ISDs should reflect the volatility over the entire remaining life of the option. If option premiums and ISDs do not adequately reflect anticipated volatility, the options would be mispriced and arbitrage opportunities would exist. If the ISD is low (high), i.e., the option is underpriced (overpriced), traders could purchase (sell) options against opposite underlying futures positions. Continuous arbitraging of mispriced options should eventually reduce the frequency of any inefficiencies in the options markets.

In this study, two approaches are used to test the predictability of ISDs on variability of futures price for the remaining life of the option. First, a correlation analysis based on the methodology of Latane and Rendleman (1976) was conducted. Their study on options introduced the concept of using implied standard deviation (ISD) to predict future stock price variability. The analysis entails simple correlations between ISDs in time t and historical standard deviations (HSD) with various leads and lags. The test is based on the notion that traders should be reflecting forecasts of the standard deviation of futures returns over the remaining life of the option in current option premiums; and, therefore, in the ISD. Traders make good forecasts of variance in markets in which ISDs are highly correlated with future HSDs. If this correlation is low, forecasts of the standard deviations are inferior. Option markets in which ISDs are highly correlated with contemporary or lagged HSDs reflect historical occurrences, rather than being anticipatory.

In this study ISDs and HSDs were calculated for each contract as discussed in the next section. The HSDs were calculated for each day using a 20-day standardized deviation of futures returns.[6] Once calculated, the HSDs were lagged for durations of $t - 1$, $t - 2$, $t - 5$, and $t - 10$ in terms of days (i.e., lagged HSDs). The contemporary standard deviation was the HSD in time t. In addition, "leading" HSDs were derived as HSDs in periods $t + 1$, $t + 2$, $t + 5$, and $t + 10$, i.e., the contemporary observation (t) was lagged by 1, 2, 5, and 10 days relative to the HSDs to derive leading HSDs, or what may be referred to as near future and long-run future volatilities (see in Latane and

[4]Pricing American futures options as European options (see Merton (1973), Hauser and Neff (1985), Asay (1982), and Wolf (1982)) introduces biases in the ISD. A study by Park and Sears (1985) suggests that although the Black model may need refinements for pricing the American options, results support the usage of ISD as an *ex ante* measure of volatility.

[5]There are many types of market efficiency tests. In the finance literature the test of market efficiency is a test of: (1) the information reflected in the price as shown by Fama (1976); and/or (2) the speed of information adjustments in the price. This study falls into the first category which includes numerous studies (see Glassman (1987)). The second category is an alternative approach and includes "event study methodology" and hedging simulation. These tests of efficienty are also joint tests because they depend on assuming a model.

[6]Results using alternative time periods (e.g., 30 and 40 days) in calculation of the HSDs were similar and are not presented here.

Rendleman (1976)) relative to time t. Each of these series of observed volatilities were then correlated with the ISDs to assess their relationship to determine which (lead or lag) is of relatively greater importance.

The second approach follows studies on stock options (see Chiras and Manaster (1978), Beckers (1981)) which established that the information content of the implied volatility should explain the future stock price volatility. Heaton further demonstrated, by using "sufficient statistics," that historic standard deviations do not improve the forecast of stock price variability when ISD has already been utilized.[7] In this study, a test procedure similar to that of Heaton (1986) and Beckers (1981) is developed and used. The following regression models are used as part of the test procedure:

$$\mathrm{ASD}_{it} = \beta_0 + \beta_1 \mathrm{ISD}_{it} + e_{it} \tag{2}$$

$$\mathrm{ASD}_{it} = \delta_0 = \delta_1 \mathrm{ISD}_{it} + \delta_2 \mathrm{HSD}_{it-n} + E_{it} \tag{3}$$

where ASD_{it} is the actual realized standard deviation of the underlying futures contract for the ensuing life of the option i (i.e., future volatility when viewed forward from t, calculated over the period from t to maturity);[8] ISD_{it} is the implied standard deviation of the underlying futures contract for option i; HSD_{it} is the historical standard deviation of futures prices for option i lagged n-days before time t; and e_{it} and E_{it} are residual terms.

There are two implications if the implied standard deviation sufficiently captures all relevant information about variability of the futures price over the remaining life of the option (ASD). First, e_{it} should be a random noise term. Second, when an additional variable (e.g., HSD) is added to eq. (2) to yield eq. (3), the resultant residual term E_{it} (an unexplained part of the future standard deviation) should not be significantly reduced in size relative to e_{it}, given ISD alone explains most of the variation in ASD. Thus, a statistic can be constructed to test the difference between the size of these two error terms. Size is represented by the absolute value of the error term. The size of error term e_{it} and E_{it} for option i at time t is $|\hat{e}_{it}|$ and $|\hat{E}_{it}|$, respectively, where $\hat{e}_{it} = \mathrm{ASD}_{it} - (\hat{\beta}_0 + \hat{\beta}_{1_{\mathrm{ISD}it}})$ from eq. (2), $\hat{\mathrm{E}}_{\mathrm{it}} = \mathrm{ASD}_{it} - (\hat{\sigma}_0 + \hat{\sigma}_1 \mathrm{ISD}_{it} + \hat{\sigma}_2 \mathrm{HSD}_{it-n})$ from eq. (3), and $\hat{\beta}_0$, $\hat{\beta}_1$, $\hat{\sigma}_0$, $\hat{\sigma}_1$, and $\hat{\sigma}_2$ are least squares estimates from eq. (2) and (3).

If the ISD in eq. (2) provides sufficient information on ASD, the difference in the absolute error term DAE (i.e., $\mathrm{DAE} = |\hat{\mathrm{e}}_{it}| - |\hat{\mathrm{E}}_{\mathrm{it}}|$) should not be significantly different from zero. If DAE is random noise, a conventional t-statistic can be used to test whether its mean (DAE) is zero by invoking the central limit theorem. However, the data used in this study are time-series and DAE has autoregressive properties. To account for the autoregressive properties, the test statistic was derived as follows. The value of DAE_{it} was derived for each observation with a mean across the time series equal to DAE. Under the assumption of a first order autoregressive structure in DAE, the following regression was estimated:

$$\mathrm{DAE}_{it} = \alpha_0 + \alpha_1 \mathrm{DAE}_{it-1} + \mu_t \tag{4}$$

where μ_t is the random term with zero mean and constant variance, ϕ^2. The t-statistic to test the mean of DAE to be zero, is constructed as:

$$t = \frac{\mathrm{DAE}}{(\phi/\sqrt{n}} \tag{5}$$

[7]Discussion of sufficient statistics using regression estimation can be found in Zellner, (1983) (pp. 120–23).

[8]ASD, as used here, is the same as SSD in Beckers (1981). Precise interpretation and calculation is shown in eq. (7) below.

where $\hat{\phi}$ is the estimated standard deviation of μ_t and n is the sample size. This same procedure was used under the assumption of second and third order autoregressive structures and results from each are reported. In those cases eq. (4) becomes:

$$\mathrm{DAE}_t = \alpha_0 + \sum_{i=1}^{a} \alpha_i \mathrm{DAE}_{t-i} + \mu_t \tag{6}$$

where a is the order of the autoregression.

The above test was used in the present study because it is more general than others. Furthermore, this test is valid even under conditions in which regression results may suffer from instability of coefficients and severe autocorrelation problems. Heaton demonstrated that in the case of stocks the error terms were autocorrelated and coefficients unstable, thereby precluding the use of traditional testing procedures.

Previous authors (see Latane and Rendlemen (1976)) have indicated that not all strike prices have the same response to volatility changes. In particular, at-the-money options with long periods to maturity are most sensitive; whereas, in-the-money options close to maturity are least sensitive. Consequently, to calculate the ISD, they suggested using a weighting scheme across strike prices according to the first derivative of the premium with respect to the standard deviation. This weighting scheme puts most of the weight on the at-the-money option.

Due to the general lack of trading in agricultural options in the time period of this study, there was little trading activity in strike prices different than those at-the-money. On many trading days, volume was zero and premiums were not even quoted for some contracts. Consequently, weighting would have been meaningless and many missing observations would be incurred. Therefore, only those strike prices closest to the underlying futures (i.e., at-the-money options) were used in this analysis. This follows Beckers (1981).[9] A simulation study by Ramaswamy and Sundaresan (1985) confirmed minimal bias in Black's European futures option model for pricing at-the-money American options. Ball and Torous (1986) also used at-the-money ISDs as an *ex ante* assessment of future price volatility.

Distortions may arise in this type of analysis because of the nonsynchronous measurement of observing closing futures and option prices. Closing prices for the futures and options are used in this analysis. Since these reported prices may be nonsynchronous (as would be the case if transaction prices were used) and due to the highly sensitive nature of the Black pricing model in deriving ISD to small changes in "closing" prices, discrepancies may be inherent. Closing prices are those at which the last trade took place, which may not have been determined simultaneously with the closing futures price. To resolve the issue of potential distortions due to not using transaction data, or synchronization of option and futures prices, the analyses were conducted using a five-day moving average of the ISD.[10] This follows Beckers (1981) who found that using an intertemporal arithmetic average of ISD performed superior to using ISD from a single day. The rationale of this approach is that the markets' estimate of volatility reflected in the option prices "fluctuates widely from day to day" which suggests that the market overreacts to new information if a single data observation is used. Ultimate resolution of this problem would require using transaction data for options and futures, which is impos-

[9]Beckers (1981) demonstrated that introducing additional options worsened the performance of the model and his results questioned the usefulness of weighing scheme in computing ISDs.

[10]Daily ISDs were also analyzed using these procedures and the results are similar to those using a five-day average of ISD.

sible. Beckers' (1981) results were similar to those using actual transaction prices on stock options when the intertemporal averaging procedure described above was used.

DATA AND SCOPE OF ANALYSIS

The major grain and oilseed commodities have options being traded on their respective futures contracts. For the purpose of this study, one contract month was chosen for each of the major grain and oilseed markets in which options were traded. A single contract month was analyzed (rather than aggregating across contract months) because the nature and extent of informational flows and volatility differ depending on contract month. Conclusions have to be restricted to these contract months. To allow as long a time period as possible for study, the most deferred month coinciding with the new crop of each commodity was chosen. Use of options in new-crop months requires traders to forecast volatilities throughout the preplanting, planting, growing, and harvest stages of the information cycle. Variances for new crop options thus should reflect the anticipation and resolution of this supply and demand information (see Anderson (1985)).[11] The contract months included in the results reported here were the contracts for November, 1985 and 1986 Chicago Board of Trade (CBT) soybeans, December, 1985 and December, 1986 CBT corn, July, 1985 and 1986 wheat at the Kansas City Board of Trade (KCBT), and July, 1985 and September, 1986 wheat at the Minneapolis Grain Exchange (MGE).

Option premiums were collected on a daily basis which was the unit of observation for this study. The time period for the analysis varied by exchange depending on the commencement of trading. In each case, data were used up to and including the last day of options trading. Only call options were used due to the general lack of trading volume in puts during this time period. Conducting tests for two recent contract years allows an evaluation of how the market performance may have changed since commencement of option trading.

Inputs required to calculate the implied standard deviation include: the actual option premium, strike price, underlying futures price, interest rates, and time-to-maturity $(T - t)$. Option premiums were obtained from daily reporting sheets at each of the exchanges. Time-to-maturity was measured as calendar days. The interest rates on Treasury Bills were from the *Wall Street Journal* and updated daily.[12]

The dependent variable in eqs. (2) and (3), ASD_{it}, is the actual volatility of the futures realized over the remaining life of the option and was calculated as the standard deviation of the daily futures returns over this period.

$$\mathrm{ASD}_{it} = \sqrt{360}\sqrt{\frac{\sum_{t=0}^{T}(R_t - R)^2}{n-1}} \tag{7}$$

where $R_t = \log(P_f/P_{f-1})$ and P_f is the underlying futures price. The Σ is from time t until maturity of the option, T, and R is calculated over the same period. For each trading day ASD was recalculated to allow for the reduction in n. Calculated as such, ASD rep-

[11]For comparison, volatilities for an old crop contract month in the U.S. (e.g., May soybeans) would largely reflect resolution of post-harvest demand from the U.S. and new-crop Southern Hemisphere supply conditions.

[12]The risk-free rate, r, is computed as:

$$r = (10{,}000/\mathrm{TB})^{360/(T-t)} - 1$$

where TB (Treasury Bill price for the time period closest to maturity of the option) is calculated as 10,000 $[1 - (i/100)\,((T - t)/360)]$; $T - t$ is time-to-maturity; and i is the average of the bid and ask discounts (in percent) [Wolf (1982)].

Table I
MEANS FOR SELECTED TIME SERIES

	CBT Corn December		CBT Soybeans November		KCBT Wheat July		MGE Wheat	
							July	September
	1985	1986	1985	1986	1985	1986	1985	1986
ASD-Actual standard deviation	.179	.261	.182	.194	.094	.379	.083	.241
ISD-Implied standard deviation	.146	.207	.174	.165	.107	.205	.085	.224
HSD_{20}-Historical standard deviation	.140	.212	.168	.183	.084	.245	.071	.228
n	171	237	228	235	152	123	152	127

Note: n is the number of observations.

resents the *ex post* actual realized volatility of the futures over the remaining life of the option looking forward from time t. To preclude any bias associated with insufficient data during the last trading days of each option, the 15 observations prior to expiration were deleted in the regression used to calculate the test statistic. However, they were not deleted in derivation of ASD.

The implied standard deviation, ISD, (i.e., that implied in the option premium) represents the volatility that the market expects to be realized. Thus, it is the expectation of the volatility. Implied standard deviations were calculated for each option using an iterative solution to the Black pricing model. The right-hand side of the Black pricing model in eq. (1) was equated with the actual call prices within $\pm .0001$ for each observed call price.

Historical standard deviations (HSDs) are commonly used as input to option pricing models. HSDs were calculated here for each day using a 20-day standardized deviation of futures returns. For robustness, the sufficient statistic test was calculated using both HSD_{t-1} and HSD_{t-10} in separate regressions in eq. (3) and derivation of the test statistic.

Sample means for each data series are shown in Table I. The actual realized standard deviation (ASD) exceeded both the ISD and the HSD for each of the CBT corn and soybean contracts. The results were mixed in the wheat contracts. The ISDs were comparable to the ASDs in 1985; but, for both exchanges, the ASD increased relative to the ISD in 1986. For demonstration purposes, Figures 1 and 2 show the behavior of the ASD and the ISD from the first observation to the last for the 1986 soybean and MGE wheat. In early trading on soybean options, ISD was less than ASD, but these differences diminished as maturity approached. The ASD for MGE wheat increased from .25 to .32 decreasing thereafter to about .12. However, ISD increased continually over the time period and exceeded the ASD even as maturity approached. Though not shown, the behavior of the standard deviation for CBT corn was similar to that of CBT soybeans. That of KCBT wheat was similar to MGE wheat, except convergence was observed in the former.

RESULTS

The results following the Latane and Rendleman (1976) procedure are presented first. This is a simple correlation analysis between the ISDs and HSDs with various leads and

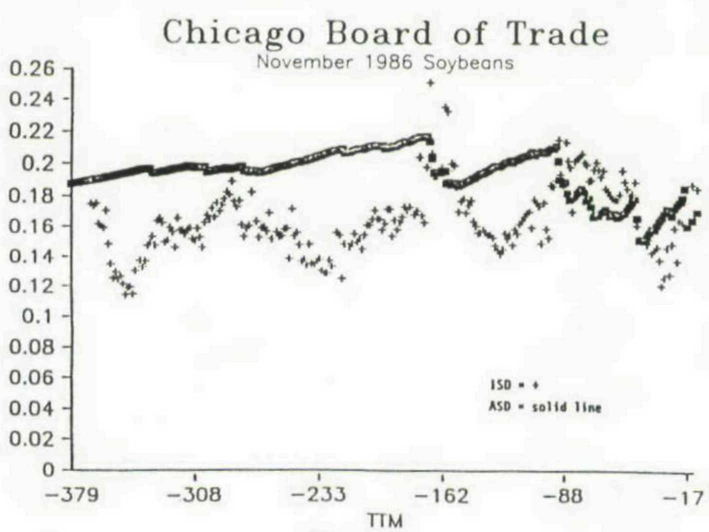

Figure 1

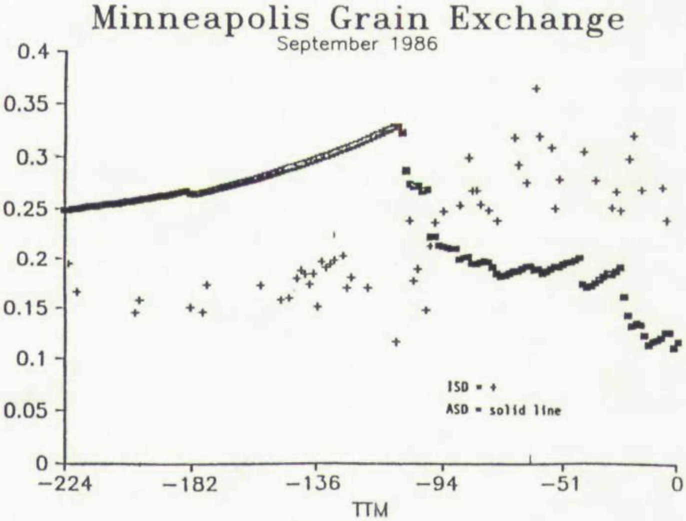

Figure 2

lags in days, and provides a test of the ability of traders to estimate volatility. Because the Black model uses *ex ante* estimates of volatility, the ISDs should reflect the expectation of future events affecting volatility, therefore, greater correlations of ISD with leading HSDs, i.e., vis-a-vis lagged HSDs, is expected.[13] The results are shown in Table II. There is relatively high correlation between the HSDs and ISDs at three of the options markets, but a low and generally insignificant correlation at the KCBT in 1985. Overall, these correlations were similar in 1986 but relatively lower in 1985 compared to studies in mature stock option markets (see Latane and Rendleman (1976), they had correlations of 0.7 to 0.8). The correlations for CBT soybeans are highest at $t + 2$ for 1986 and $t + 10$ for 1985 and generally decline thereafter. The correlation for CBT corn is highest during $t + 1$, $t + 2$, and $t + 5$ in 1986; and $t + 1$, t, and $t - 1$ in 1985. This result indicates that corn option investors are anticipatory. The correlations for MGE wheat are distinctly highest at t, $t - 1$, $t - 2$, and $t - 5$ for 1985, and $t - 10$ for 1986. The correlations decline for other durations. Some of the correlations with lagged HSDs at KCBT wheat in 1985 are negative and in all cases not significantly different than zero. However, in 1986 these correlations became positive and significant with peaks occurring during t, $t + 1$, and $t + 2$.

In general, relatively low correlations are suggestive that in grains and oilseeds as opposed to stocks, traders' estimates of volatility as reflected in option premiums, are less accurate. The corn and soybean markets are consistent with expectations (see Latane and Rendleman (1976)). The soybeans options market is quite anticipatory, indicating that it consistently anticipates events affecting volatility as compared to the other markets. Corn is also an anticipatory market, but with a very slow and undefined time horizon. The wheat markets are not consistent with either expectations or similar studies on stock markets. The options in 1985 at the KCBT market did not capture the price volatility of futures nor anticipate changes. However, in 1986, correlations were positive and forward looking. Options on MGE wheat are more reflective of price volatility, but not anticipatory. This suggests that, at least in the wheat market, traders are shortsighted; or, in the extreme, do not reflect estimates of volatility in option premiums.

[13]The terminology used by Latant and Rendleman (1976) is near future and long-run future volatilities, vs. historical volatilities.

Table II

CORRELATION COEFFICIENTS BETWEEN IMPLIED STANDARD DEVIATIONS (ISD_{L5}) AND HISTORICAL STANDARD DEVIATIONS OF VARIOUS LEADS AND LAGS

Lead & Lag Period For Historical Standard Deviations	CBT Corn December		CBT Soybeans November		Wheat: Kansas City Board of Trade July		Wheat: Minneapolis Grain Exchange July	Wheat: Minneapolis Grain Exchange September
	1985	1986	1985	1986	1985	1986	1985	1986
$t + 10$	.35*	.61*	.40*	.67*	−.04	.73*	.23*	.05
$t + 5$	.39*	.65*	.28*	.83*	−.01	.94*	.25*	.22
$t + 2$	.41*	.65*	.23*	.85*	.02	.96*	.28*	.29*
$t + 1$	.42*	.65*	.21*	.84*	.05	.96*	.29*	.30*
t	.42*	.64*	.20*	.83*	.07	.96*	.30*	.35*
$t - 1$	.42*	.64*	.20*	.80*	.05	.95*	.31*	.39*
$t - 2$	.41*	.63*	.20*	.77*	.02	.93*	.31*	.42*
$t - 5$	.35*	.60*	.19*	.62*	−.09	.80*	.31*	.51*
$t - 10$	.19*	.50*	.15*	.29*	−.19	.57*	.22*	.66*

*Significant at the 10 percent level.

Note: Corrrelations between various leads and lags of observed standard deviation and ISD_{L5} (five-day moving average of ISD) are shown in the vertical column. For MGE market individual daily ISD is used in the correlation analysis instead of five-day average of ISD due to missing observations.

The remainder of the analysis examines the functional relationships between ASD (the actual realized standard deviation of stock price returns over the remaining life of the option) and ISD and HSD_{t-n}. Stability tests of the coefficient values are first presented. Results for the modified Heaton's test statistic are then presented and interpreted. Results are presented using HSDs lagged 1 and 10 days, respectively. Beckers (1981) and Heaton (1986) each used $t - 1$ in their analyses which were averaged using monthly data. Each of these tests are undertaken along the same theme of option market efficiency. Robustness is assured by conducting a multitude of tests with similar variables.

Coefficients in the regression models (where ASD is regressed on ISD and HSD) may not be stable as suggested by Heaton (1986). To test the hypothesis that the coefficients are stable, the data were divided in two equal parts. Results of the Chow test for stability of coefficients are shown in Table III. In all cases, the null hypothesis that there is no difference in coefficients between the two sample periods is rejected. Thus, the functions estimated for the two time periods are significantly different indicating the relationship changes through time.

This test analyzes whether inclusion of an additional variable (eq. (3)) provides more information about ASD than captured in the simple relationship (eq. (2)). The error structures from eqs. 2 and 3 were generated from the regression models and the t-statistics are computed and results are shown in Table IV. In all cases the test statistic is significant at the 5 percent level in both years.[14] Thus, the null hypothesis that the HSDs (i.e., HSD_{t-1} or HSD_{t-10}) do not improve the forecast is rejected. Forecasts of the actual volatility over the remaining life of an option (ASD) generated from an equation including both ISD and HSD, are superior to forecasts using ISD alone. These results indicate that the ISD captures insufficient information about ASD and that incorporating data such as HSD improves the forecast of the actual volatility over the remaining life of the contract.[15]

Assuming the options market is dominated by traders who behave as though they use the Black model, these results indicate that not all available information was reflected in the option price in either 1985 or 1986 for the particular contracts analyzed. Consequently, there is reasonable evidence to argue that option premiums are not properly

Table III
TEST OF EQUALITY OF REGRESSION COEFFICIENTS

Commodity/Exchange	*F*-Statistic 1985 Contracts	*F*-Statistic 1986 Contracts
CBT corn	12.75*	57.6*
CBT soybeans	16.94*	63.0*
KCBT wheat	15.87*	27.7*
MGE wheat	35.81*	22.8*

*Indicates significance at the 10 percent level.

Note: Regression coefficients were derived from $ASD_t = \beta_0 + \beta_1, ISD + \beta_2 HSD_{t-10}$.

[14]Models using higher order autoregressive structures were also tested and the results are not different from those presented here.

[15]Results for the 1986 MGE wheat are not reported due to insufficient data. The procedure requires a substantial number of consecutive observations due to the lagging which is conducted. However, MGE wheat trading in 1986 was abnormally sparse and after the appropriate lags there were only eight observations in the sample which would render the results unreliable.

Table IV
TEST OF PREDICTIVE IMPROVEMENT (*t*-statistics shown)

Autoregressive Structure	1985 Contracts Soybeans	Corn	Wheat KCBT	Wheat MGE	1986 Contracts Soybeans	Corn	Wheat KCBT
First							
HSD_{t-1}	6.01	15.65	6.31	4.48	2.80	16.93	6.30
HSD_{t-10}	10.42	13.18	6.09	8.55	2.79	7.41	5.38
n	196	145	110	140	191	169	38
Second							
HSD_{t-1}	3.31	15.54	2.02	4.72	2.77	17.70	5.51
HSD_{t-10}	5.73	13.09	1.96	8.71	2.76	9.75	4.71
n	194	142	104	139	186	162	33
Third							
HSD_{t-1}	6.26	15.37	5.93	4.58	2.72	17.98	5.62
HSD_{t-10}	10.77	12.95	5.72	8.74	2.71	7.43	4.81
n	192	139	98	138	181	155	30

priced in these contracts and markets. Due to this mispricing arbitrage profits (excluding transaction costs) could likely result in these agricultural contracts. As Black (1976) showed, arbitrage profits could be realized by taking appropriate positions in futures and bond markets to replicate the option payoff. For example, suppose traders can forecast the futures price volatility better than ISD. When the ISD is low (i.e., option is underpriced), they should buy options and simultaneously create an appropriate portfolio of short commodity futures/long bonds to replicate the option payoff. Opposite positions could be taken if the forecasted standard deviation was lower than that reflected in ISD. Because futures and bond transactions can cover the option transaction, no additional funds are tied up while profits are generated.

SUMMARY

The standard deviation implied in option premiums (ISD) should be anticipatory of volatility in futures returns over the remaining life of the contract. Latane and Rendleman (1976) suggested that if option premiums are properly priced, ISDs derived in option premiums should be anticipatory. In other words, traders should be reflecting forecasts of future standard deviation in current option premiums. Previous studies in the stock option market have generally confirmed that these markets are efficient. The ISD should be sufficient to capture information regarding ASD (i.e., no other information can be used to systematically improve forecasts of actual volatility over a forecast using ISD alone) and can be tested by comparing forecasts generated with and without inclusion of some measure of historical volatility. The intent is to evaluate whether current option premiums anticipate volatilities.

In this article two types of analyses were undertaken to evaluate option pricing efficiency in selected agricultural options contracts. The first indicated that the correlation between the historical standard deviation (HSD) and ISD are positive and anticipatory for CBT corn and soybean markets. However, correlations in the wheat market between HSD and ISD were either insignificant (and negative in some cases) or positive and backward-looking. Although the ISD in the CBT corn and soybean markets performs better than in the wheat markets at the two exchanges (because of the positive and forward-looking correlation), it does not necessarily mean that corn and soybean markets are efficient. In fact, as shown in the second test, all markets including corn and soybeans were inefficient in processing relevant information in 1985 and 1986. Results imply that for some contracts analyzed here, the option premiums have been systematically mispriced because ISDs derived here have not captured sufficient information regarding the actual volatility.

Market participants should be aware of these phenomena when using options for risk management. Traders can earn riskless profits excluding transactions costs if the option payoff is replicated by trading a portfolio of options, futures, and bonds. Given that the efficient market test is a joint test, i.e., the efficiency of the market per se and the validity of the model used, questions concerning the robustness of the model should be raised because the Black model has certain restrictive assumptions such as nonstochastic interest rate, the European feature, and certain stochastic processes. However, if the Black model is assumed correct, interpretation of the results in this study implies that the markets are not capturing the expected information affecting the variability of futures price.

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