Options-Based Forecasts of Futures Prices in the Presence of Limit Moves

Thorsten M. Egelkraut[a,*]

and

Philip Garcia[b]

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[a,b]Thorsten M. Egelkraut and Philip Garcia are Graduate Fellow and Professor and T. A. Hieronymus Chair in the Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign. The authors are also in the Office of Futures and Options Research.
[*]Corresponding author: egelkrau@uiuc.edu; Tel.: +1-217-333-0644; Fax +1-217-333-5538; Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, 326 Mumford Hall, MC-710, 1301 West Gregory Drive, Urbana, Illinois 61801, USA.

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This analysis examines a simultaneous estimation option-based approach to forecast futures prices in the presence of daily price limit moves. The procedure explicitly allows for changing implied volatilities by estimating the implied futures price and the implied volatility simultaneously. Using 15 years of futures and futures options data for three agricultural commodities, we find that the simultaneous estimation approach accounts for the abrupt changes in implied volatility associated with limit moves and generates more accurate price forecasts than conventional methods that rely on only one implied variable.

Keywords: Implied futures price, Forecast, Limit move, Options implied volatility, Simultaneous estimation

Introduction

In order to protect investors' equity against contract default, some futures exchanges impose voluntary daily price limits within which trades may occur. Once the futures price has increased (decreased) to the upper (lower) bound, no trading at higher (lower) prices is possible until the futures price reverses back into the permissible range, or until the next trading day when new limits are set. Whenever trading is ceased, the futures price stops reflecting the market's assessment of the "true" price of the contract. The futures market becomes informationally inefficient because investors are prevented from incorporating publicly available information into prices. Yet, since limit moves are generally associated with the arrival of new information and the resolution of great amounts of uncertainty, knowing the new "true" price level during this particular time is especially critical for investors and has important consequences for efficient derivative pricing and effective hedging decisions.

Options markets can provide an alternative way to obtain the subsequent futures price, even when the underlying contract has stopped trading. The traditional approach involves inserting the last recorded non-limit futures and options prices in a theoretical options pricing formula such as Black's (1976) model and solving for the implied volatility. At the halt of trading in the underlying futures, this volatility estimate can be used together with a current options price to obtain an implied futures price. The implied price reflects investors' assessment of what the "true" futures price would be if no price limits were in place. However, this traditional approach can result in inaccurate price estimates because the implied volatility is assumed to remain constant when trading is halted. Empirical research has shown that the arrival of new information alters the amount of uncertainty that investors expect to be resolved until option expiration and results in significant changes of the options implied volatility (Patell and Wolfson, 1979; McNew and Espinosa, 1994; Donders and Vorst, 1996; Ederington and Lee, 1996).

We propose and empirically test an alternative approach to obtain futures price estimates in the presence of limit moves. The procedure explicitly incorporates changing implied volatilities by estimating the implied futures price and the implied volatility simultaneously. Pedersen (1998) cautions that such simultaneous estimation of two parameters can dilute available information from the options market by introducing an additional source of error. In the presence of limit moves better implied volatility estimates however may have the potential to outweigh this possible bias and result in more accurate implied futures prices than with traditional approaches. Using an extensive data set and the recently advanced *MDM*-test, we examine this hypothesis for three agricultural commodities - corn, soybeans, and hogs - which frequently reach daily price limits. If successful, the proposed approach will be a valuable tool for investors and decision-makers, not only in agricultural futures markets but also other futures markets, to obtain accurate price estimates when futures trading is temporarily ceased.

Literature Review

Price limits establish upper and lower bounds of the daily price range within which trading of a particular futures is permitted. These exchange mandated limits are intended to reduce the risk of contract default by preventing market overreaction and providing traders with additional time to adjust to new information. The effectiveness of price limits has been widely debated in the financial literature. Early researchers such as Ma et al. (1989a, b) report that price restrictions do in fact moderate volatility. Their results are in contrast to more recent empirical studies that associate limits with an increase in volatility (Kuhn et al., 1991; Lee et al., 1994; Kim and Rhee, 1997). Yet, regardless of the impact on volatility, limits prevent prices from reaching their equilibrium level and leave investors uncertain about the “true” price.

Information about the approximate price level however is available from the options market as futures prices are also embedded in options premiums. If an estimate of the implied volatility exists, a theoretical options pricing model can be inverted and solved for the implied futures price. But in the presence of limit moves using the implied volatilities at the halt of trading to recover futures prices is problematic because the underlying assumption that the implied volatility remains unchanged may not hold.

Limit moves are usually associated with the arrival of new information that significantly deviates from market expectations. As investors incorporate the new information into prices, uncertainty is either resolved or created. During scheduled news events, uncertainty is generally removed and implied volatility drops because the timing of the release is known a priori. In contrast, unexpected news announcements frequently add uncertainty to the market and cause investors to revise their future volatility expectations upward (Ederington and Lee, 1996). Both cases result in a change of the options implied volatility. One of the first studies by Patell and Wolfson (1979) analyzing the implied volatilities of stock options on 28 major corporations finds a ‘dramatic decline’ in implied standard deviations during the two-day earnings announcement period with the strongest decrease observed for nearby options. More recently, Donders and Vorst (1996) evaluate 96 scheduled corporate news disclosures and report that after a news release call option implied volatility ‘drops sharply.’ Examining the informational content of USDA crop reports for corn and soybeans, McNew and Espinosa (1994) observe similar changes in implied volatility for two agricultural markets. For both commodities, they observe an immediate ‘drop’ in implied volatility after the production estimates are announced. Ederington and Lee (1996) contrast scheduled and unscheduled macroeconomics news releases in the T-Bond, Eurodollar, and Deutschemark options market and conclude that implied volatility decreases following scheduled and increases following the unscheduled announcements.

To account for such abrupt shifts in implied volatility procedures must rely on the information conveyed by several options and solve for two implied variables – volatility and futures price – instead of the implied futures price alone. Simultaneous estimation approaches have been shown to produce efficient estimates of, for example, foreign currency exchange rates (Tucker, 1987) or soybean futures prices (Sherrick et al., 1996). In a direct comparison with the traditional Black and Scholes (1973) framework Pedersen (1998) finds however that solving for two variables simultaneously can introduce new sources of error and dilute available information. Yet, in the presence of limit moves, better implied volatility estimates may have the potential to outweigh the possible bias and result in more accurate futures price estimates than would be obtained using traditional approaches.

Methods

Traditional Futures Price Forecasts

An option’s present value is its expected future payoff at maturity discounted at the risk free rate. Following Black’s (1976) standard formula, the current premiums of European call and put futures options can be written as

$$B_c(f_t, s, x, r, t) = e^{-rt}\left[f_t N(d_1) - xN(d_2)\right] \qquad [1]$$

$$B_p(f_t, s, x, r, t) = e^{-rt}\left[xN(-d_2) - f_t N(-d_1)\right] \qquad [2]$$

where

$$d_1 = \frac{\ln\left(\frac{f_t}{x}\right) + \frac{s^2 t}{2}}{s\sqrt{t}} \quad \text{and} \quad d_2 = \frac{\ln\left(\frac{f_t}{x}\right) - \frac{s^2 t}{2}}{s\sqrt{t}},$$

f_t is the futures price at time t, s is the instantaneous standard deviation of future returns, x is the option’s strike price, r is the risk-free interest rate, t is the time to expiration ($T-t$), and N(.) is the standard normal cumulative distribution function. Although commodity futures options are frequently American rather than European type, the associated pricing error is small and at a minimum for at-the-money options so that the model serves as a good approximation (Ramaswamy and Sundaresan, 1985; Barone-Adesi and Whaley, 1987). When trading in the underlying futures contract is unrestricted, the only unobservable variable in Equations 1 and 2, the future volatility, can be obtained by inverting the relationship and solving for the standard deviation. Following Jorion (1995) and others, the implied volatilities of the nearest-to-the-money call and the nearest-to-the-money put are averaged to minimize further possible measurement errors.

On limit days, when futures trading has ceased, this volatility estimate is reinserted into the above relationship and the formula solved for the implied futures price as a prediction of the subsequent futures price. Employing this procedure, we generate three traditional forecasts of the futures price. The first is based on the call option with a strike nearest to the last recorded futures price (CIF), i.e. the upper or lower limit, and the second is based on the put option with a strike nearest to the last recorded futures price (PIF). This practice most closely approximates at-the-money conditions at times when limits are reached. To further reduce possible errors, a third futures price estimate is computed as the arithmetic average of the call and put implied futures prices (AVIF).

Simultaneous Estimation Approach

Forecasts of the futures price can also be generated by an approach that estimates the implied futures price and the implied volatility simultaneously. Using premiums of options with identical maturity but different strikes, we solve Black's (1976) option pricing model simultaneously for the implied volatility and the implied futures price by minimizing the sum of squared pricing errors in

$$\min_{j}\left[\sum_{i=1}^{k}\left(P_{c,i}-B_{c,i}\left(j,x_i,r,t\right)\right)^2+\sum_{j=1}^{l}\left(P_{p,j}-B_{p,j}\left(j,x_j,r,t\right)\right)^2\right] \qquad [3]$$

where j is the two-dimensional parameter vector containing the implied volatility and the implied futures price, $P_{c,i}$ and $P_{p,j}$ are the observed call and put option premiums, $B_{c,i}$ and $B_{p,j}$ are the theoretical option premiums based on Black's (1976) model in Equations 1 and 2, x_i and x_j are the respective call and put strike prices, and k and l are the number of calls and puts used to estimate the parameter vector. Hence, the simultaneous estimation approach in Equation 3 uses the market's entire information set to obtain futures price forecasts by including all calls and puts across all strike prices. Because the simultaneous estimation approach (SEA) does not require an observed futures price, it can incorporate more recent volatility information when estimating the implied price.

Forecast Evaluation

No arbitrage conditions imply that the expected return from holding futures contracts is zero. Therefore, implied futures prices can be interpreted as forecast of future futures prices. In this study, we consider the first recorded non-limit futures price as the future futures price, which serves as a reference in assessing the predictive accuracy of each forecasting technique.

The accuracy of all futures price forecasts is evaluated based on relative forecast errors using mean absolute percentage errors (MAPEs) and mean squared percentage errors (MSPEs)

$$MAPE=\frac{1}{n}\sum_{i=1}^{n}\left|\frac{\left(f_{IMPLIED,i}-f_{NON-LIMIT,i}\right)}{f_{NON-LIMIT,i}}\times 100\right| \qquad [4]$$

$$MSPE = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{\left(f_{IMPLIED,i} - f_{NON-LIMIT,i}\right)}{f_{NON-LIMIT,i}}\times 100\right)^2 , \qquad [5]$$

where $f_{IMPLIED}$ refers to a particular futures price forecast (CIF, PIF, AVIF, or SEA), $f_{NON-LIMIT}$ to the first recorded non-limit price, and where n, the total number of observations, depends on the commodity examined. These error measures are then compared for different forecasts using the Modified Diebold Mariano (*MDM*) test proposed by Harvey, Leybourne, and Newbold, HLN (1997). The procedure involves specifying a cost-of-error function, *g(e)*, of the forecast errors *e* and testing pair-wise the null hypothesis of equality of expected forecast performance. The test statistic, which HLN (1997) indicate should be compared with the critical values from the Student's *t* distribution with (T – 1) degrees of freedom, is computed for one-step ahead forecasts as

$$MDM = \sqrt{\frac{T-1}{\frac{1}{T}\sum_{t=1}^{T}\left(d_t - \bar{d}\right)^2}}\,\bar{d} , \qquad [6]$$

where $d_t = g(e_{t,1}) - g(e_{t,2})$, $\bar{d}$ is the average difference across all years, and the null hypothesis is $E(d_t) = 0$. For example, when testing for significant differences of the MAPEs of two forecasts, $g(e_{t,1})=|e_{t,1}|$ is the absolute percent forecast error of method 1, $g(e_{t,2})=|e_{t,2}|$ is the absolute percent forecast error of method 2, and $d_t = e_{t,1} - e_{t,2}$ is the difference between the respective absolute percent forecast errors at time *t*.

HLN (1998) demonstrate that the size of the *MDM* test is insensitive to contemporaneous correlation between the forecast errors, and that its power declines only marginally with departures from normality. They argue that these characteristics are important since researchers attempting to differentiate between forecasts are often faced with correlated forecasts that possess occasional large errors. Other advantages of the *MDM* test include its applicability to multiple-step ahead forecast horizons, its non-reliance on an assumption of forecast unbiasedness, and its applicability to cost-of-error functions other than the conventional quadratic loss. HLN (1997) assert that the *MDM* test constitutes the "best available" method for determining the significance of observed differences in competing forecasts.

Data

This analysis uses daily open, high, low, close, and settlement prices of corn, soybean, and hog futures and futures options from January 2, 1987 to December 31, 2001, providing 15 years of observations. The data for corn and soybeans are obtained from the Chicago Board of Trade (CBOT) and those for hogs from the Chicago Mercantile Exchange (CME). These commodities were selected because their options markets displayed large trading volume across all strike prices. A summary for each commodity is presented in Table 1.

CBOT regulation 1008.01 prohibits corn and soybean futures and options trading at a price higher or lower than plus or minus the specified daily limit of either the previous day's settlement price or the average of the opening range. Futures limits are lifted two business days before the beginning of the contract month and options limits on the last trading day. For hogs, CME rule 15202.D states that trading ceases at a price more than the predefined daily limit above or below the settlement price on the previous business day. No limits are in effect in the spot month during the last two trading days and for options.

Most limit moves of corn, soybeans, and hog futures are triggered by news announcements such as crop production forecasts or hogs and pigs reports. Both are released either before the open or after the close of trading.[1] Therefore, we select for analysis from the data set: (1) the non-limit closing prices of futures and options on the day before a limit-open, (2) opening options prices on the limit-open day (for corn and soybeans, only options that opened within their daily price range are used), and (3) the first non-limit futures price, which is either the first non-limit open price on the trading day following a limit-close or, if the futures price reverses back into its daily range, the current upper or lower price limit (Figure 1). To minimize distortions resulting from trading activity close to expiration and from low liquidity, the options selected have between one and six months until expiration. If several contracts meet this requirement, the nearby maturity is chosen to avoid double-counting. Based on these criteria, a total of 26 limit moves are observed for corn, of which 15 were up and 11 were down limits, 20 for soybeans (14 up and 6 down limits), and 36 for hogs (20 up and 16 down limits) (Table 1).

The options data are next filtered to exclude uninformative observations. Such observations include (1) options that are listed but did not actually trade, i.e. zero volume observations, (2) options violating monotonic strike price patterns, and (3) options with prices less than three times their minimum tick size. The first criterion is used because options prices with no associated trades are simply price quotes. As such, they are not the result of a (negotiation) process in which market participants reach an agreement on their value and form a common volatility expectation. The second criterion removes options that are inconsistent with monotonic strike prices. Call premiums must decrease with increasing strike price and put premiums must increase with increasing strike price. The third criterion avoids possible distortions of the implied volatility calculation introduced by the discrete nature of market prices.

The non-limit closing prices of the futures and the nearest-to-the-money call and put on the day before a limit-open are used to obtain the estimate of the implied volatility within the framework of Equations 1 and 2. On the actual limit-open day, this implied volatility serves as the basis for computing the three alternative forecasts of the futures price from the call and put options with strikes nearest to the last recorded futures price, i.e. the upper or lower limit. A fourth futures price forecast is calculated using the simultaneous estimation approach in Equation 3 and based on all valid opening options prices on the

[1] Crop production reports are released at 8:30 am EST (3:00 pm EST before 1995) and hogs and pigs reports are released at 3:00 pm EST by the National Agricultural Statistics Service (NASS), U.S. Department of Agriculture.

limit-open day. Finally, all forecasts are compared to the first non-limit futures price and evaluated with respect to their predictive accuracy.

Results

Table 2 displays the mean absolute and the mean squared percentage errors of all forecasting approaches. The magnitudes of the error measures show that during limit moves investors have greater difficulties assessing the movement of corn and soybean futures prices than of hog futures prices. This finding is not surprising for two reasons. First, the size of the daily price limit represents a larger fraction of the average corn and soybean prices than of the average hog price. Second, all but a few limit moves in the corn and soybean futures markets fall into periods of typically high volatility (Egelkraut et al., 2003). This elevated volatility reflects investors' great uncertainty about the impact of stochastic environmental factors on crop growth and future yield, and indicates that with or without price limits, market participants have difficulty in agreeing on a futures price. Subsequent forecast errors are therefore larger in corn and soybeans than in hogs where less seasonality in the volatility is present.

Evaluating the accuracy of each forecasting procedure, we find that for all commodities the simultaneous estimation approach (SEA) returns the most accurate predictions of the futures price. This approach generates the smallest forecast errors for corn (MAPE=1.450 and MSPE=4.968), soybeans (MAPE=1.532 and MSPE=4.642), and hogs (MAPE=0.796 and MSPE=1.349). The average of the call and put implied futures prices (AVIF) is the second best predictor, while using only one option, call (CIF) or put (PIF), produces less informative forecasts (Table 2). Hence, the improvement in predictive accuracy achieved by averaging the call and put implied futures prices is not sufficient to compensate for error introduced by the imprecise implied volatility estimate ($MAPE_{SEA}<MAPE_{AVIF}$; $MSPE_{SEA}<MSPE_{AVIF}$).

Using the MDM test, the MAPEs and the MSPEs of each method are compared more formally. The error function *g(e)* is specified as the absolute and the squared percent forecast error and tests for statistical significance in the differences of the MAPEs and the MSPEs between the simultaneous estimation approach and each of the alternative practices. For corn, the *p*-values reported in Table 3 show that for both specifications of the error function, all differences between the MAPEs and MSPEs are significant. For soybeans and hogs, significant differences are found between the MAPEs and MSPEs of SEA and CIF, while the test results for SEA and PIF as well as SEA and AVIF are mixed. The lack of consistent statistical significance in the latter differences between the SEA and the PIF and AVIF is related to a few large errors which disproportionately affect the *MDM* results. In sum, our findings indicate that in the presence of limit moves the simultaneous estimation approach outperforms the alternative predictors of subsequent futures price.

Conclusion

This analysis examines a simultaneous estimation approach against alternative predictors of the subsequent futures price for times when the actual futures has reached its daily price limit and trading is ceased. The procedure explicitly incorporates changing implied volatilities by estimating the implied futures price and the implied volatility simultaneously. Using 15 years of futures and futures options data on three agricultural commodities, corn, soybeans, and hogs, we find that the simultaneous estimation approach accounts for the abrupt changes in implied volatility associated with limit moves and generates more accurate price forecasts than the alternative methods considered. In spite of Pedersen's (1998) observation that such simultaneous estimation of two parameters can dilute the information available from the options market by introducing an additional source of error, our results imply that in the presence of limit moves, better implied volatility estimates outweigh any added bias and result in more accurate implied futures prices.

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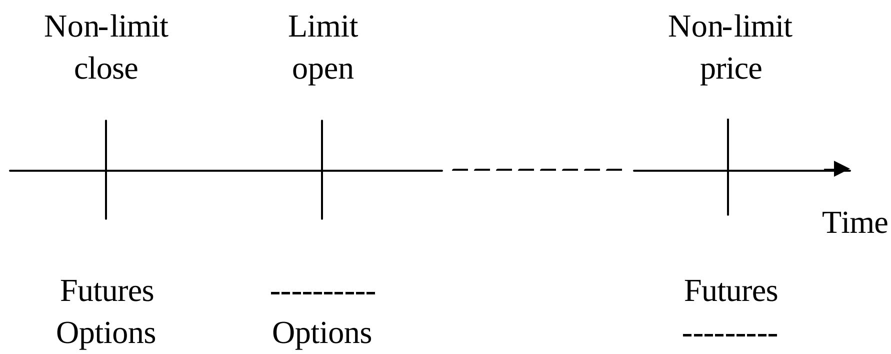

Figure 1. Futures and futures options data used on each limit move.

Table 1. Contract months, current daily price limits, and number of limit moves.

Commodity	Contract Months[b]	Current Daily Price Limit	Limit Moves		
			Up	Down	Total
Corn	Z,H,K,N,U	$0.20 per bu[d,e]	15	11	26
Soybeans	U,X,F,H,K,N,Q	$0.50 per bu[d,f]	14	6	20
Hogs[a]	G,J,K[c], M,N,Q,V,Z	$0.02 per lbs[g]	20	16	36

[a]The Dec 96 contract were the last live hog futures and the Feb 97 contract the first lean hog futures traded.

[b]F=January, G=February, H=March, J=April, K=May, M=June, N=July, Q=August, U=September, V=October, X=November, Z=December

[c]May options were introduced by the CME in 2001.

[d]Until July 10, 2002, if three or more corn or soybean contracts of the same year reached their daily price limits, the limits were expanded 150% for the next two trading days.

[e]For corn, the daily limit was raised on March 12, 1992, from $0.10 to $0.12 per bu, and on July 10, 2000, from $0.12 to $0.20 per bu.

[f]For soybeans, the daily limit was raised on July 10, 2000, from $0.30 to $0.50 per bu.

[g]For hogs, the daily price limit was raised from $0.015 per lb to $0.020 per lb beginning May 6, 1996, for lean hogs only (February 1997 contract months and beyond). The limit remained at $0.015 per lb for live hogs (December 1996 months and before).

Table 2. Forecast errors of the simultaneous estimation approach and alternative methods in predicting the futures price in the presence of limit moves

Commodity	Error[a]	Implied Futures Price Forecast[b]			
		SEA	CIF	PIF	AVIF
Corn	MAPE	1.450	2.230	2.544	1.769
	MSPE	4.968	8.693	10.317	6.084
Soybeans	MAPE	1.532	2.645	1.998	1.659
	MSPE	4.642	11.307	6.002	5.371
Hogs	MAPE	0.796	1.311	1.790	1.201
	MSPE	1.349	3.257	8.344	3.110

[a]MAPE and MSPE are the mean absolute and mean squared percentage errors.

[b]SEA are the forecasts based on the simultaneous approach in Equation 3. CIF, PIF, and AVIF are the forecasts based on Equations 1 and 2, using a single call option, a put option, and the average of the implied futures of these call and put options, with a strike nearest to the last recorded futures price.

Table 3. *p*-values of Modified Diebold Mariano (MDM) test for statistical significance in the mean absolute percentage errors and mean squared percentage errors between simultaneous estimation approach and alternative methods

Commodity	Error[a]	SEA[b]		
		CIF	PIF	AVIF
Corn	MAPE	0.013	0.001	0.051
	MSPE	0.000	0.000	0.001
Soybeans	MAPE	0.017	0.181	0.663
	MSPE	0.000	0.100	0.001
Hogs	MAPE	0.002	0.009	0.032
	MSPE	0.017	0.120	0.129

[a]MAPE and MSPE are the mean absolute and mean squared percentage errors.

[b]SEA are the forecasts based on the simultaneous approach in Equation 3. CIF, PIF, and AVIF are the forecasts based on Equations 1 and 2, using a single call option, a put option, and the average of the implied futures of these call and put options, with a strike nearest to the last recorded futures price.