SUCCESS AND FAILURE OF AGRICULTURAL FUTURES CONTRACTS, HOW TO BEST PREDICT SEMIVARIANCE, AND GARCH OPTION PRICING WITH IMPLIED VOLATILITY

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PREFACE

This thesis consists of three separate essays. The first essay is titled "Success and Failure of Agricultural Futures Contracts". This first essay seeks to determine the factors that contribute to the success and failure of agricultural futures contracts. Commodities with futures markets as well as commodities without futures markets were selected and analyzed with respect to characteristics of futures contracts success and failure. One of the primary contributions of this essay is that unlike past research, it includes not only non-traded commodities but it also includes characteristics that are difficult to measure, and have been ignored in the past. This essay uses the Delphi technique to obtain a cardinal measure of those characteristics. Those characteristics include homogeneity, vertical integration, activeness of the cash market, and buyer concentration. A simple linear model is used in this first essay to capture the relationship between futures contracts volume (and open interest) and a set of factors suspected to contribute to contract success.

The second essay, titled "How to Best Predict Price and Yield Risk with Risk Measured as Semivariance", seeks to determine the relative accuracy in predicting price and yield risk of three approaches: the first approach uses an empirical distribution function to predict risk; the second approach assumes normality and considers the first two moments; and the third approach incorporates third and fourth moments. The second essay was motivated by comments of seminar audiences and reviewers that only downside movements should be used as a measure of risk. To the extent that those comments are accurate, they cast doubt on measures of risk that include only upside movements and those that include both upside and downside movements. In this essay, risk is defined as squared deviations below a target. A tobit model is provided to capture the relationship between squared deviations below a target and the predictions obtained from the different approaches. Root mean squared errors and "encompassing regression analysis" were used to assess the performance of each approach.

The third essay titled "GARCH Option Pricing With Implied Volatility" seeks to determine whether a generalized autoregressive conditional heteroskedasticity (GARCH) option pricing model with implied volatility provides a more accurate forecast of option premia than the Black option pricing model with implied volatility. This essay improves on previous research in that, the GARCH parameters on lagged variance and lagged error are estimated from historical data, and then the unconditional volatility is estimated given the GARCH parameters by minimizing the sum of squared errors. Implied volatilities are estimated for the Black option pricing model. The unconditional volatility are then used to forecast next day option premia. Forecasts of next-day option premia were also obtained for the Black implied volatilities. Root mean squared forecast errors were used to assess the forecasting performance of both GARCH and Black option pricing models with implied volatility. The results can provide guidance to option traders.

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Finally, I would like to dedicate this research to the memories of my mother Amani Aya and my father Nayeba Fofana, who brought me into this world but did not live long enough to witness the achievement of their son.

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ESSAY ONE

SUCCESS AND FAILURE OF AGRICULTURAL FUTURES CONTRACTS

SUCCESS AND FAILURE OF AGRICULTURAL FUTURES CONTRACTS

Abstract

The objective of this study is to determine the factors contributing to the success or failure of agricultural futures contracts. Commodities with futures markets and commodities without futures markets were selected and analyzed with respect to their product homogeneity, vertical integration, buyer concentration, activeness of their cash market, cash price variability, ability to attract hedgers and speculators, and size of their cash market. Homogeneity, vertical integration, buyer concentration, and activeness of the cash market were measured by the Delphi technique. Results suggest that the structure of the marketing channel, the size of the cash market, the activeness of the cash market, the effectiveness of the grading system (homogeneity), liquidity cost, the ability of the own hedge market to bear more risk than the existing cross hedge market, and cash price variability are important in the success or failure of futures contracts. Moreover, activeness of the cash market is a necessary condition for futures contracts success. Results also suggest that none of the non-traded commodities considered is likely to have a successful contract if it were traded; since, they do not have a very active cash market.

Key words: Active cash market, buyer concentration, Delphi technique, Futures contracts, homogeneity, open interest, selectivity, vertical integration.

SUCCESS AND FAILURE OF AGRICULTURAL FUTURES CONTRACTS

Introduction

With free markets comes price variability. Price volatility makes future agricultural returns uncertain and thus, there may be a need for new agricultural futures contracts. The break down of the former Soviet Union has led many countries (Eastern European countries as well as other countries around the world) to move toward market economy. Many of those countries are considering the development of futures markets. Beside the need to develop new futures markets, recent market structure changes (for example, vertical integration), that cause cash markets to disappear, are raising questions on the viability of futures markets. Trading on futures markets developed from the need to improve trading infrastructures such as communication, weight and measures, grades and standards, storage, transport, inspection, and to facilitate trade (Telser and Higinbotham). The existence of uncertain future prices was also a motive for futures trading (Cornell). This argument is supported by Grossman (1977) who showed that differing beliefs in the capability of market prices to provide perfect information will lead to futures trading. The idea is also supported by Carlton (1983) who argued that futures markets arise as a response to economic uncertainty. Working (1953), in claiming that futures trading exist primarily to facilitate hedging and speculation, was supportive of that theory. Futures contracts are traded on futures markets. Over 180 different futures contracts have existed from 1921 to 1983 (Carlton, 1984). Unfortunately, the majority of futures contracts fail within 10 years of their introduction. Indeed, Silber estimates that between two-thirds and three-quarters of new contracts fail to attract and sustain a profitable level of trading volume. By recent estimates, only 3 in 10 new futures contracts become profitable (Kolb, 1991). Factors contributing to the success or failure of futures contracts, are unclear (Kolb). However, there is evidence that cash market size, risk reduction ability of the contract, cash price variability, and liquidity costs influence volume of trade and open interest of futures contracts (N'Zue and Brorsen). A successful contract is one that maintains a consistently high volume of trade and open interest (Black). Hence, determining factors contributing to the success of agricultural commodities futures contracts is equivalent to determining factors affecting their (agricultural commodities futures contracts) volume of trade and open interest. Commodity exchanges and professionals in futures markets need to know why futures markets succeed or fail when they are developing new futures contracts. Countries that are considering the development of a futures market need to know elements or conditions necessary to the existence of a successful futures market. The present research seeks to determine factors that contribute significantly to the success or failure of agricultural commodities futures contracts. Past research on success and failure of futures contracts have focused on non-agricultural commodities (Black 1986). N'Zue and Brorsen analyzed factors affecting volume of trade and open interest of agricultural commodities futures contracts. Their study was limited to successful contracts (contracts that are currently traded). They did not account for variables such as homogeneity, vertical integration, buyer concentration, and activeness of the cash market. The present research extends the study by N'Zue and Brorsen to include homogeneity, vertical integration, buyer concentration, activeness of the cash market, commodities without futures markets and also futures contracts that failed (futures contracts that existed but are not currently traded).

Procedures

From the list of criteria considered necessary for selecting commodities and contracts for futures trading (Kolb; Carlton (1984); Tomek and Gray (1970); Sandor (1973); Pierog and Stein (1989); and Gray (1966)) and following Black's argument that exchanges seek to maximize member's utility, and that member's utility is positively related to futures contracts volume, the following characteristics were selected as important to the success or failure of agricultural commodities futures contracts:

a. The own hedge contract bearing less risk than the existing cross-hedge contract for commodity I.

b. The volatility of the cash market price for commodity I ($PVAR_i$).

c. The liquidity cost of using the own futures market instead of the existing cross-hedge futures market for commodity I ($CLIQ_i$).

d. The size of the cash market for commodity I ($SIZE_i$).

e. The structure of the marketing channel (vertical integration (VI_i), and buyer concentration (BCR_i)).

f. Activeness of the cash market for commodity I (ACM_i).

g. The homogeneity characteristic (grading effectiveness) of commodity I (HOM_i).

The above characteristics are used as variables important to the success or failure of agricultural futures contracts. These variables are discussed below.

Relative Residual Risk (RR)

The relative residual risk is obtained by estimating the following equation:

$$\Delta Cash\ Price_i = \alpha + \beta(\Delta Futures\ Price_i) + \epsilon_i \tag{1}$$

where Δ represents weekly changes[1], α and β are parameters to be estimated. The coefficient of determination (R^2) of the above equation is used as a measure of risk reduction (Black). That is, ($1-R^2$) is a measure of the risk that remains in a futures contract (residual risk). The relative residual risk is calculated as the ratio of the residual risk of the cross hedge market (alternative market) and that of the own hedge market (cross hedge markets for the commodities selected are presented in table 2). For commodities without futures markets, relative residual risk was calculated using the average R^2 obtained for commodities with futures markets[2]. The coefficient of this variable is expected to be positive. That is, a relatively high relative residual risk (greater than one) means cross-hedging bears more risk than own-hedging. If that is the case, own-hedge market is preferred to cross-hedge market, and contract volume and open interest in own-hedge market increase.

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[1]Cash market for feeder cattle and live cattle operate only on Monday's and on Tuesday's, hence, weekly cash price changes are computed as the difference between prices of two consecutive Mondays.

[2] Relative residual risk (RR) = $1 / (1 - R^2)$

Cash price variability (PVAR)

The cash price variability is obtained by taking the standard deviation of the weekly cash price change and dividing it by the contract size. For commodities where daily or weekly cash prices were not available, monthly cash price changes were calculated. The variance of the monthly cash price change was then transformed to obtain a weekly variance. The transformation is as follows:

$$VAR\ (\Delta WEEK\ ) = \frac{VAR\ (\ \Delta MONTH\ )}{T}. \tag{2}$$

T is the number of weeks in a month and it assumed to be 4. Δ is the symbol for change and VAR is the symbol for variance. The standard deviation of cash price change is obtained by taking the square root of the weekly variance. Literature on futures markets shows a strong positive correlation between price volatility and trading volume.

Liquidity cost (CLIQ)

Liquidity cost is measured as the average weekly trading volume of all active months in the cross-hedge futures market. It (liquidity cost) captures the relative cost of using the existing cross hedge futures contract versus the new own hedge market. Since hedgers compare the liquidity of the cross hedge and own hedge markets in choosing a hedging vehicle, the existing cross hedge market (which is well established, accepted and liquid) will be preferred. Black argued that the more liquid the cross hedge market, the more costly (in terms of foregone liquidity) is own hedging. Thus, the success of new contracts should be inversely related to liquidity cost. In a recent article, Tashjian and Weissman argued that highly correlated and even redundant sets of contracts may be successful. The idea is that a set of contracts that contains correlated contracts (the soybeans complex for example) can, at the optimal level of transaction fees, generate more revenue than a set of contract without correlated contracts. Thus, highly correlated contracts may be successful. Black's argument and that of Tashjian and Weissman are not exclusive as they may appear. Both arguments are based on the activeness of the underlying market. In Tashjian and Weissman argument, the markets considered are assumed liquid and very active, whereas in Black's argument, newly developed contracts are less active and less liquid. Both arguments state implicitly how important is the activeness of the underlying market in the success of new futures contracts.

Cash market size (SIZE)

The annual production[3] of each commodity was used as a measure of the size of the cash market. For live hogs, commercial hog slaughter was used as an indication of production. For live cattle, slaughter steers and heifers of 500 pounds and over were used as an indication of live cattle production. For feeder cattle, the following formula was used to calculate annual production:

(3) $$PRODUCTION_t = COW\ CALF_t + FS_{bt} - FS_{et}$$

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[3]Production data were obtained from various issues of USDA's agricultural Situation and Outlook.

where $PRODUCTION_t$ is annual production, $COW\ CALF_t$ is annual cow calf supply, FS_{bt} is the beginning feeder supplies as of January 1 of current year, and FS_{et} is the ending feeder supplies as of January 1 of following year. The annual production of each commodity was then divided by the contract size of the futures contract of that commodity. Production units and contract size of the selected commodities are given in table 3.

Homogeneity (grading effectiveness)

Futures contracts are defined as a legal agreement to buy or to sell a given quantity and quality of a commodity at a specified price at the time the contract is executed (Chicago Board of Trade). A commodity whose quality is subjective or depends on individual taste will not be easy to grade and hence, it will not be suitable for futures trading. Black gives the example of tobacco as a commodity whose quality variation is so high that a successful tobacco futures market is unlikely. Moreover, Hieronymus (1972) argued that units of commodities traded on futures markets must be interchangeable. That is, the commodity must be describable. Thus, homogeneity is an important feature in the success or failure of agricultural commodities futures contracts. It (homogeneity) is subjective. Different degrees of homogeneity exist making it difficult to measure. But it is not because a characteristic is subjective or difficult to measure that, it has to be ignored. For the present research, homogeneity is defined as the effectiveness of the grading system and it is hypothesized to be positively related to trading volume and open interest. A grading system is effective if the grades adequately explain differences in value. Grading effectiveness will be measured by the Delphi approach.

Market structure

The structure of the marketing channel of commodities across all levels can influence the likelihood of success or failure of commodities futures contracts. Market structure is an important factor in the success or failure of futures contracts. Preventing exercise of market power through contract design increases the likelihood of success of futures contracts. Two measures of market structure were considered (vertical integration and buyer concentration).

Vertical integration

In the present research, vertical integration includes both ownership and contract integration. The degree of vertical integration depends on the number of pricing points and the percentage of the commodity which is priced at each point. Only pricing points where the form of the commodity is not changed are considered. Some commodities (live cattle for example) have only one pricing point where form is not changed (from feedlot to packer). Whereas others (wheat, corn, etc...) have multiple pricing points where their form is not changed. The more pricing points without form being changed, then the less vertical integration. Vertical integration is measured by the Delphi approach. Vertical integration is hypothesized to be negatively correlated with volume of trade and open interest.

Buyer concentration

Concentration is defined as the percent of the commodity handled by the largest firms. For commodities with multiple pricing points (wheat, corn, etc..), concentration indicates an average concentration across buyers. For commodities with single pricing point (live cattle for example) only buyer concentration is considered. Buyer concentration is measured with the Delphi technique. Buyer concentration is hypothesized to be negatively correlated with volume of trade and open interest.

Activeness of cash market

The activeness of a market is determined by the percentage of market participants quoting bids and offers and the frequency with which they are quoted. An active cash market will be one in which market participants quote bids and offers daily. We hypothesize that commodities without an active cash market will be unlikely to have a successful futures contract. The more active a market, the higher is its ability to attract hedgers and speculators. Moreover, there is a positive correlation between activeness of a commodity's cash market and its volume of trade and open interest. This argument is supported by Black p.46 who stated that "A heavily traded market enables a market maker to absorb larger orders without much risk. It is probable, then, that the quoted spread will be good for larger volume than in a less active market." Peterson, Lehman and Thompson in their discussion at the NCR-134 conference In Chicago, Illinois (April 24-25, 1995) are supportive of that idea. The activeness of the cash market is measured with the Delphi technique.

The Delphi technique

The Delphi technique is a group process that allows those individuals who possess the knowledge and ability and may be located in different geographical areas to contribute meaningfully in solving a given problem (Render and Stair, and Stevenson). The problem in our case is to measure homogeneity, vertical integration, buyer concentration, and the activeness of the cash market. A scale of one to 10 was developed to rate each commodity (for example, in the case of homogeneity, one means the commodity considered is not homogeneous, whereas 10 means that it is). Then a panel of respondents was selected (The panel list is given in appendix). The respondents were given a questionnaire/survey on which they were asked to rank each commodity using the scale of one to 10. The final Data and detail of the questionnaire/survey can be found in appendix. The mean (μ) and the mean +/- one standard deviation ($\mu \pm \sigma$) of the estimates obtained from the first round were computed. In the second round the respondents were asked to reevaluate their estimates and to give a brief explanation of their new estimate if it is outside the $\mu \pm \sigma$ interval. The procedure was repeated three times and the mean of the estimates of the third round was taken as the measure of the homogeneity characteristic. The first and final rounds survey are presented in appendix (See Shannon for details on the Delphi technique).

Data

Daily closing prices (prices are roll-forward one year with no adjustment), cash prices, total volume (VOL_i), total open interest (OI_i), and future price changes for January 15, 1987 to December 31, 1992 were obtained for commodities with futures markets and used in computing estimates. The data were created using Continuous Contractor from Technical Tools. The contract month is January, and the day is day 15 of previous month.

Cash price changes were also computed. The changes in future and cash prices were used to compute weekly future and cash price changes. For non-traded commodities, monthly prices were collected from various issues of the United State Department of Agriculture's (USDA) agricultural situation and outlook. The data set includes agricultural commodities and livestock as described in table 1.

Model

Because of the commodities without futures markets (no trading volume nor open interest), the simple log linear model used in N'Zue and Brorsen is no longer appropriate. A tobit model is also not appropriate since futures contracts volume and open interest are really not negative, it is just that futures markets do not exist and hence, volume and open interest cannot be observed. A selectivity model was chosen as the appropriate alternative. The selectivity model is defined in a general framework as follows: Suppose we have two variables y^*_t and z^*_t such that

(4)
$$\begin{aligned} y_t &= y_t^* \quad \forall \quad z_t^* > 0; \quad y_t = 0 \quad \forall \quad z_t^* \leq 0; \\ z_t &= 1 \quad \forall \quad z_t^* > 0; \quad z_t = 0 \quad \forall \quad z_t^* \leq 0. \end{aligned}$$

where y^*_t, and z^*_t are generated by the bivariate process

(5)
$$\begin{bmatrix} y_t^* \\ z_t^* \end{bmatrix} = \begin{bmatrix} X_t'\beta \\ W_t'\gamma \end{bmatrix} + \begin{bmatrix} \mu_t \\ \nu_t \end{bmatrix}$$
$$\begin{bmatrix} \mu_t \\ \nu_t \end{bmatrix} \sim NID\left(0 \, , \begin{bmatrix} \sigma^2 & \rho\sigma \\ \rho\sigma & 1 \end{bmatrix} \right)$$

where X'_t, and W'_t are vectors of observations on exogenous variables, β and γ are unknown parameter vectors, σ is the standard deviation of μ_t and ρ is the correlation between μ_t and v_t. The restriction that the variance of v_t is equal to 1 is imposed because only the sign of z^*_t is observed (Davidson and MacKinnon). Equation (4) suggest two types of observations: one for which both y_t and z_t are observed to be zero and one for which $z_t = 1$ and $y_t = y^*_t$. Heckman (1976) suggested a simple method for obtaining estimates of selection models. The method known as the Heckman's two step method is based on the fact that the first equation in (4) can be rewritten as

$$(6) \qquad y_t^* = X_t\beta + \sigma\rho v_t + e_t$$

replacing y^*_t by y_t and v_t by its mean conditional on z_t=1 and on the realized value of $W'_t\gamma$, we can rewrite equation (6) as

$$(7) \qquad y_t = X_t\beta + \rho\sigma \frac{\phi(W_t'\gamma)}{\Phi(-W_t'\gamma)} + e_t$$

The quantity $\phi(W'_t\gamma)/\Phi(-W'_t\gamma)$ is known as the inverse Mills ratio. Equation (7) is referred to as the selection equation. The first step in Heckman's method is to use a probit model to obtain consistent estimates of the selection equation. In the second step, equation (7) is estimated by ordinary least squares (See Davidson and Mackinnon and also Greene; Judge et al. for more details on selectivity models). If we let $y_t = (VOL_{it}$ or $OI_{it})$, $W_t = (PVAR_{it}$, $SIZE_{it}$, VI_{it}, BCR_{it}, ACM_{it}, $HOM_{it})$, and $X_t = (RR_{it}$, $CLIQ_{it}$, $PVAR_{it}$, $SIZE_{it}$, VI_{it}, BCR_{it}, ACM_{it}, $HOM_{it})$ then, we can write equation (7) as a function of the variables specified above. For the present research, the selection model was estimated using Kmenta's Cross-sectionally heteroskedastic and timewise autoregressive method (POOL command in SHAZAM). The general specification of the models will be:

(8) $$VOL_{it} = f(RR_{it}, \ln(CLIQ_{it}), PVAR_{it}, \ln(SIZE_{it}), VI_{it}, BCR_{it}, ACM_{it}, HOM_{it})$$

(9) $$OI_{it} = f(RR_{it}, \ln(CLIQ_{it}), PVAR_{it}, \ln(SIZE_{it}), VI_{it}, BCR_{it}, ACM_{it}, HOM_{it})$$

where ln is the symbol for natural logarithm and the subscript *I* and *t* refer to commodity and time respectively. A simple estimated generalized least squares (EGLS) procedure was then used to obtain parameter estimates of equations (8) and (9). Two different specifications of the general model were estimated. The estimated models were labeled A, and B for Volume of trade, and C, and D for open interest. Specifications A and C include all of the variables whereas specifications B and D do not include the vertical integration variable. Vertical integration is excluded because it is highly correlated with the buyer concentration variable. Means across years of predicted volume and open interest for both traded and non-traded commodities were obtained for models B and D.

Empirical Results

Primary estimation results provided evidence against the existence of a selection problem. The active cash market variable alone gave a perfect fit to the probit equation (first step in the Heckman approach). This results suggest that activeness of the cash market is extremely important to the success of futures contracts. Moreover, it is "impossible" (except for few commodities) for a futures market to exist without the existence of an active cash market. Other results are summarized in tables 2, 3, 4, 5, 6, 7 and 8. Table 2 presents the mean across years of futures contracts trading volume and open interest of selected commodities in contracts per week, and the cross hedge market for the selected commodities. Corn and soybeans have the highest weekly average volume and open interest. Feeder cattle and pork bellies have the lowest weekly average volume and open interest. The cross hedge markets were selected based on the closeness of those markets to the own hedge markets.

Table 3 shows the production and price units of selected commodities with their associated futures contracts size. For non-traded commodities, potatoes and orange juice contract sizes were used as proxy.

Table 4 presents the means of the survey variables for the selected commodities. The first and final round of the survey are presented in appendix. It appears from table 4 that none of the non-traded commodities has an active cash market. Indeed, those commodities were given a rank below five by the panel of expert used in the survey. Most of those commodities (except milk) have a very concentrated market.

Table 5 summarizes the correlation matrix of the surveyed variables. The correlation coefficients suggest that homogeneity is not highly correlated with the other variables surveyed. The correlation coefficients also suggest that vertical integration variable is highly correlated with both the buyer concentration variable and the active cash market variable. The high positive correlation between vertical integration and buyer concentration may indicate that those two variables are measures of the same thing. That, is the reason underlying the re-specification of the initial model without the vertical integration variable. Moreover, the negative correlation between buyer concentration and active cash market suggest that the more buyers are concentrated in a market, the less active that market will be. As argued in the primary estimation results, activeness of the cash market is a necessary condition for the success of futures contracts. Therefore, a commodity with a less active cash market is inclined to fail. The importance of an active cash market to the success of futures contracts found in this research is consistent with Black's argument that trading in a very active market far more favorable than trading in an inactive one. It is also consistent with the assumptions underlying Tashjian and Weissman argument that highly correlated and even redundant set of contracts may be successful. Indeed, unless the highly correlated set of contracts has a very active cash market, it will be inclined to fail.

Table 6 presents the EGLS parameter estimates of the futures contracts volume models. The estimates of specification B suggest that cash price volatility, relative residual risk, cash market size, liquidity cost, homogeneity, buyer concentration and the activeness of the cash market contribute significantly to futures contract volume. Results in table 6 are consistent with those found by N'Zue and Brorsen. Moreover, results show significant positive correlation between active cash market and futures contracts volume (assuming that the cash market is sufficiently active). That is, a sufficiently active cash market is a necessary condition for successful futures contracts.

Table 7 presents the parameter estimates of the open interest models. Results in specification D suggest that cash market size, liquidity cost, homogeneity, and buyer concentration contribute significantly to futures contract open interest.

The homogeneity variable has a consistently positive parameter estimate for both volume and open interest. That is, a commodity's grading effectiveness is important to the success of its underlying futures contract. This may explain why commodities such as tobacco and tea (just to cite a few) are not traded. In both the volume and open interest models, the parameter estimates of buyer concentration are consistently negative which may suggest the failure of futures contracts (or potential problems) in highly concentrated markets (the cattle market).

Table 8 shows means across year of predicted volume and open interest for both traded non-traded commodities. Predicted open interest for pork bellies is negative. Result that suggest potential problems in the pork bellies market. Among the non-traded commodities, tomatoes has the highest predicted volume and open interest. This result suggest that a futures contract on tomatoes is likely to succeed. However, it is important to refer to the activeness of the cash market for tomatoes. Based on the survey result, the tomatoes market cannot be characterized as active. Hence, a futures contract in that market is not likely to succeed.

Concluding Comments

A simple linear model was used to determine factors important to the success or failure of agricultural futures contracts. Commodities with and without futures markets were selected. The results suggest that a futures contract cannot exist for a commodity (except the sugar contract) unless the commodity considered has an important cash market size, volatile cash price, effective grading system, and most importantly an active cash market. The changing structure (i.e. buyer concentration, vertical integration) in the market for some commodities (livestock for example) will create a decline in the futures contracts volume and open interest and thereby cause the failure of those contracts. Implications of this research for countries who are considering developing their own futures markets is that, unless an active cash market exists, resources invested in developing futures markets will be wasted. Moreover, those countries should first direct their effort toward developing active cash markets and effective grading systems, and then consider the possibility of developing a futures markets. These implications also apply to commodity exchanges in identifying new futures contracts, and the Commodity Futures Trading Commission (CFTC) in deciding which proposed contracts to approve. Results also suggest that none of the non-traded commodity considered is likely to have a successful contract if it were traded; since the cash market is not very active for those commodities. For those commodities which have a cash market active enough to support a futures market, other factors such as cash market size, liquidity cost, market structure, and grading system effectiveness have to be considered before introducing a futures contract.

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Table 1. Commodities Included in the Study, and Time Period Covered.

Commodities	Period
Agricultural Commodities:	
1. Chicago Wheat	1987-1992
2. Kansas City Wheat	1987-1992
3. Minneapolis Wheat	1987-1992
4. Corn	1987-1992
5. Soybeans	1987-1992
6. Soybean Meal	1987-1992
7. Soybean Oil	1987-1992
8. Cotton	1987-1992
9. Apples	1987-1992
10. Pears	1987-1992
11. Tomatoes	1987-1992
12. Rice	1987-1992
13. Sunflower seed	1987-1992
14. Potatoes	1987-1992
15. Onions	1987-1992
Livestock:	
16. Live Cattle	1987-1992
17. Feeder Cattle	1987-1992
18. Live Hogs	1987-1992
19. Pork Bellies	1987-1992
Miscellaneous:	
20. Broilers	1987-1992
21. Eggs	1987-1992
22. Milk	1987-1992
23. Nonfat Dry Milk	1987-1992
24. Cheese	1987-1992

Table 2. Mean Across Year of Futures Trading Volume of Selected Commodities in Contracts per week, and the Cross-Hedge Market for the Selected Commodities.

Commodity	Weekly Average Volume	Weekly Average Open Interest	Cross-hedge Market
Corn	198,910	990,050	Chicago wheat
Chicago Wheat	59,516	264,410	K. C. wheat
K. C.Wheat	25,003	131,330	Chicago wheat
Soybeans	191,010	542,900	Soybean meal
Soybean meal	17,928	65,599	Soybeans
Soybean oil	17,188	76,954	Soybeans
Live cattle	17,007	79,805	Feeder cattle
Feeder cattle	2,036	13,757	Live cattle
Live hogs	7,421	28,801	Live cattle
Pork bellies	4,393	12,888	Live hogs

Table 3. Production and Price Unit of Selected Commodities with Associated Futures Contract Size.

Commodity	Production Unit	Price Unit	Contract Size
K.Wheat	Million bushels	$ / bushel	5000 bushels
C.Wheat	Million bushels	$ / bushel	5000 bushels
Corn	1000 bushels	$ / bushel	5000 bushels
Soybeans	Million bushels	$ / bushel	5000 bushels
Soybeans Meal	1000 tons	$ / ton	100 tons
Soybeans Oil	Million pounds	$ / 100 lbs	60000 pounds
Feeder Cattle	1000 head	$ / pound	50000 pounds
Live Cattle	1000 head	$ / pound	40000 pounds
Live Hogs	1000 head	$ / pound	40000 pounds
Pork Bellies	Million pounds	$ / pound	40000 pounds
M.Wheat	Million bushels	$ / bushel	5000 bushels
Cotton	1000 tons	$ / 100 lbs	500 pounds
Rice	Million cwt	$ / cwt	2000 cwt
Sunflower Seed	1000 cwt	$ / cwt	1000 cwt
Milk	Billion pounds	$ / 100 lbs	150 pounds
Nonfat Dry Milk	Million pounds	$ / pound	15000 pounds
Cheese	Million pounds	$ / pound	15000 pounds
Apples	Million pounds	$ / pound	80000 pounds
Pears	1000 tons	$ / 2000 lbs	400 pounds
Tomatoes	Million pounds	$ / 100 lbs	800 pounds
Broilers	Million pounds	$ / 100 lbs	300 pounds
Eggs	Million dozen	$ / 100 doz.	225 dozen
Potatoes	1000 cwt	$ / cwt	800 cwt
Onions	Million pounds	$ / 100 lbs	80000 pounds

Notes on weights equivalents: 1 hundredweight (cwt) = 100 pounds, 1 tons = 20 hundredweight, 1 ton = 2000 pounds, 24 Million heads = 21.4 Billion pounds (CBOT, Commodity Trading Manual pp. 195), 1000 head = 891750 pounds, consequently, 1 head = 891.750 pounds. For the following commodities, POTATOES contract size was used as equivalent to their contract size: ONIONS, TOMATOES, APPLES, PEARS. For the following commodities, ORANGE JUICE contract size was used as equivalent to their contract size: MILK, NON FAT DRY MILK, CHEESE.

Table 4. Means of the Survey Data Obtained from the Delphi Technique for Homogeneity, Vertical Integration, Active Cash Market, and Buyer Concentration.

Commodity	Homogeneity	Vertical Integration	Active Cash Market	Buyer Concentration
Kansas City Wheat	8.17	2.83	8.67	3.50
Chicago Wheat	8.17	2.83	8.67	3.50
Corn	7.83	2.67	8.67	3.00
Soybeans	7.33	3.00	8.83	3.43
Soybeans Meal	8.67	3.83	7.33	5.00
Soybeans Oil	8.50	4.83	6.50	5.00
Feeder cattle	4.17	3.17	6.17	4.57
Live Cattle	4.83	5.17	6.33	6.57
Live Hogs	5.67	5.33	6.67	6.43
Pork bellies	7.00	5.00	7.33	4.86
Minneapolis Wheat	8.17	2.83	8.67	3.50
Cotton	7.33	3.17	7.50	6.33
Rice	7.83	4.83	6.00	5.86
Sunflower Seed	6.83	4.00	3.17	6.00
Milk	8.00	6.17	3.00	4.29
Non-fat-dry Milk	9.33	4.00	3.00	6.00
Cheese	6.83	4.17	3.17	6.00
Apples	4.00	5.17	4.17	5.67
Pears	3.83	4.83	3.83	6.00
Tomatoes	4.00	5.00	3.83	5.33
Broilers	7.83	9.83	1.33	8.14
Eggs	7.50	9.00	2.00	8.33
Potatoes	4.67	4.67	3.50	6.17
Onions	4.33	4.17	3.50	5.17

Table 5. Correlation Matrix of the Survey Variables

	Homogeneity	Vertical Integration	Active C. Market	BuyerConcentration
Correlation				
Homogeneity	1.000			
Vertical Integration	-0.483	1.000		
Active C. Market	0.274	-0.705	1.000	
Buyer Concentration	-0.206	0.777	-0.725	1.000

Table 6. EGLS Parameter Estimates of Futures Contracts Volume Models.

Independent Variables	Models A	Models B
Intercept	-1.164	-1.236
	(-1.069)	(-1.047)
PVAR	0.351	1.215**
	(0.525)	(1.829)
RR	6.163*	9.049*
	(2.192)	(3.134)
SIZE	2.235*	1.879*
	(5.777)	(4.676)
CLIQ	-1.375*	-1.802*
	(-2.145)	(-2.650)
HOMO	-0.064	1.721*
	(-0.069)	(2.129)
VI	51.348*	
	(3.193)	
ACM	3.492*	2.492*
	(3.264)	(2.245)
BCR	-6.147*	-1.704*
	(-3.936)	(-2.215)
R-Square	0.837	0.800

Notes: Numbers in parentheses are t-ratios.

[a] One asterisk denotes coefficients significant at 5% probability level, and two asterisks denote coefficients significant at 10 % probability level.

Table 7. EGLS Parameter Estimates of Futures Contracts Open Interest Models.

Independent Variables	Models C	Models D
Intercept	1.182	1.076
	(1.912)	(1.532)
PVAR	-0.643	5.643
	(-0.187)	(1.618)
RR	-0.588	1.174
	(-0.488)	(0.919)
SIZE	12.189*[a]	9.961*
	(6.206)	(4.648)
CLIQ	-1.222*	-1.483*
	(-3.344)	(-3.627)
HOMO	0.541	1.531*
	(1.063)	(3.021)
VI	30.771*	
	(4.029)	
ACM	0.519	-4.594
	(0.084)	(-0.669)
BCR	-4.331*	-1.589*
	(-5.479)	(-3.475)
R-Square	0.852	0.804

Notes: Numbers in parentheses are t-ratios.

[a] One asterisk denotes coefficients significant at 5% probability level, and two asterisks denote coefficients significant at 10 % probability level.

Table 8. Means Across Year of Predicted Volume and Open Interest for Both Traded and Non-Traded Commodities in Contracts Per Week.

Commodity	Predicted trading Volume	Predicted Open Interest
Kansas City Wheat	99,787	337,410
Chicago Wheat	94,419	383,680
Corn	141,390	562,510
Soybeans	153,590	541,400
Soybeans Meal	14,468	39,403
Soybeans Oil	7,408	89,204
Feeder Cattle	2,219	29,573
Live Cattle	14,056	73,126
Live Hogs	24,317	20,693
Pork Bellies	557	-9,334
Minneapolis Wheat	290	1,235
Cotton	425	1,879
Rice	224	986
Sunflower Seed	228	998
Milk	1,568	7,178
Nonfat Dry Milk	291	1,242
Cheese	267	1,147
Apples	734	3,316
Pears	1,249	5,719
Tomatoes	3,483	16,084
Broilers	1,289	5,943
Eggs	475	2,143
Potatoes	286	1,247
Onions	846	3,841

Appendix

Survey # 1

Grading effectiveness.

The following survey uses the Delphi approach to obtain a cardinal measure of the effectiveness of the grading system. A grading system is effective if the commodity is homogeneous or grades adequately explain differences in value. A scale of 1 to 10 is used to rate the degree of homogeneity. A 10 should indicate that the commodity considered is very homogeneous, and a one should indicate that the commodity considered is not homogeneous. Please circle the number (only one) that you think, best describes the degree of homogeneity of the commodities below. In your response please consider only the time period from January 1, 1987 through December 31, 1992.

Commodity	Scale									
	Lowest									Highest
Soft Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Hard Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Spring Wheat	1	2	3	4	5	6	7	8	9	10
Corn	1	2	3	4	5	6	7	8	9	10
Feeder Cattle	1	2	3	4	5	6	7	8	9	10
Live Cattle	1	2	3	4	5	6	7	8	9	10
Live Hogs	1	2	3	4	5	6	7	8	9	10
Pork Bellies	1	2	3	4	5	6	7	8	9	10

Grading Effectiveness Continued.

Commodity	Scale									
		Lowest								Highest
Soybeans	1	2	3	4	5	6	7	8	9	10
Soybean Meal	1	2	3	4	5	6	7	8	9	10
Soybean Oil	1	2	3	4	5	6	7	8	9	10
Cotton	1	2	3	4	5	6	7	8	9	10
Apples	1	2	3	4	5	6	7	8	9	10
Pears	1	2	3	4	5	6	7	8	9	10
Tomatoes	1	2	3	4	5	6	7	8	9	10
Broilers	1	2	3	4	5	6	7	8	9	10
Eggs	1	2	3	4	5	6	7	8	9	10
Milk	1	2	3	4	5	6	7	8	9	10
Potatoes	1	2	3	4	5	6	7	8	9	10
Rice	1	2	3	4	5	6	7	8	9	10
Orange Juice	1	2	3	4	5	6	7	8	9	10
Lumber	1	2	3	4	5	6	7	8	9	10
Cheese	1	2	3	4	5	6	7	8	9	10
Sunflower Seed	1	2	3	4	5	6	7	8	9	10
Non-fat Dry Milk	1	2	3	4	5	6	7	8	9	10
Onions	1	2	3	4	5	6	7	8	9	10

Thank you for your time.

Activeness of Cash Market.

The following survey uses the Delphi approach to obtain a cardinal measure of the effectiveness of the activeness of the cash market for a given commodity. The activeness of a market is determined by the percentage of market participants quoting bids and offers and the frequency with which they are quoted. An active cash market is one in which market participants quote bids and offers daily. A less active cash market is one in which fewer participants quote bids and offers or bids and offers are quoted less frequently. A scale of 1 to 10 is used to rate the activeness of the cash market of a given commodity. A 10 should indicate that the commodity considered has a very active cash market, and a one should indicate that the commodity considered does not have an active cash market. Please circle the number (only one) that you think, best describes the activeness of the cash market for the commodities below. In your response please consider only the time period from January 1, 1987 through December 31, 1992.

Commodity	Scale								
		Lowest							Highest
Soft Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Hard Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Spring Wheat	1	2	3	4	5	6	7	8	9	10
Corn	1	2	3	4	5	6	7	8	9	10
Feeder Cattle	1	2	3	4	5	6	7	8	9	10
Live Cattle	1	2	3	4	5	6	7	8	9	10
Live Hogs	1	2	3	4	5	6	7	8	9	10

Activeness of Cash Market Continued.

Commodity	Scale								
	Lowest								Highest
Pork Bellies	1	2	3	4	5	6	7	8	9	10
Soybeans	1	2	3	4	5	6	7	8	9	10
Soybean Meal	1	2	3	4	5	6	7	8	9	10
Soybean Oil	1	2	3	4	5	6	7	8	9	10
Cotton	1	2	3	4	5	6	7	8	9	10
Apples	1	2	3	4	5	6	7	8	9	10
Pears	1	2	3	4	5	6	7	8	9	10
Tomatoes	1	2	3	4	5	6	7	8	9	10
Broilers	1	2	3	4	5	6	7	8	9	10
Eggs	1	2	3	4	5	6	7	8	9	10
Milk	1	2	3	4	5	6	7	8	9	10
Potatoes	1	2	3	4	5	6	7	8	9	10
Rice	1	2	3	4	5	6	7	8	9	10
Orange Juice	1	2	3	4	5	6	7	8	9	10
Lumber	1	2	3	4	5	6	7	8	9	10
Cheese	1	2	3	4	5	6	7	8	9	10
Sunflower Seed	1	2	3	4	5	6	7	8	9	10
Non-fat Dry Milk	1	2	3	4	5	6	7	8	9	10
Onions	1	2	3	4	5	6	7	8	9	10

Thank you for your time.

Vertical Integration.

The following survey uses the Delphi approach to obtain a cardinal measure of the effectiveness of vertical integration across one or several pricing points. Vertical integration includes both ownership and contract integration. The degree of vertical integration depends on the number of pricing points and the percentage of commodity which is priced at each point. Consider only pricing points where the form of the commodity is not changed. Some commodities (live cattle for example) have only one pricing point where form is not changed (from feedlot to packer). Whereas others (wheat, corn etc...) have multiple pricing points where their form is not changed. The more pricing points without form being changed, then the lower should be the measure of vertical integration. A commodity with one pricing point, all of the commodity freely priced at that pricing point should have the same measure of vertical integration as a commodity with two pricing points and half of the commodity at each pricing points being transferred through some form of vertical integration. A scale of 1 to 10 is used to rate the degree of vertical integration. A 10 should indicate that the commodity considered has a very vertically integrated market (little or none of the commodity is priced), and a one should indicate that the commodity considered does not have a vertically integrated market (multiple pricing points). Please circle the number (only one) that you think, best describes the degree of vertical integration of firms for the commodities below. In your response please consider only the time period from January 1, 1987 through December 31, 1992.

Vertical Integration Continued.

Commodity	Scale									
		Lowest								Highest
Soft Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Hard Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Spring Wheat	1	2	3	4	5	6	7	8	9	10
Corn	1	2	3	4	5	6	7	8	9	10
Feeder Cattle	1	2	3	4	5	6	7	8	9	10
Live Cattle	1	2	3	4	5	6	7	8	9	10
Live Hogs	1	2	3	4	5	6	7	8	9	10
Pork Bellies	1	2	3	4	5	6	7	8	9	10
Soybeans	1	2	3	4	5	6	7	8	9	10
Soybean Meal	1	2	3	4	5	6	7	8	9	10
Soybean Oil	1	2	3	4	5	6	7	8	9	10
Cotton	1	2	3	4	5	6	7	8	9	10
Apples	1	2	3	4	5	6	7	8	9	10
Pears	1	2	3	4	5	6	7	8	9	10
Tomatoes	1	2	3	4	5	6	7	8	9	10

Vertical Integration Continued.

Commodity	Scale									
		Lowest								Highest
Broilers	1	2	3	4	5	6	7	8	9	10
Eggs	1	2	3	4	5	6	7	8	9	10
Milk	1	2	3	4	5	6	7	8	9	10
Potatoes	1	2	3	4	5	6	7	8	9	10
Rice	1	2	3	4	5	6	7	8	9	10
Orange Juice	1	2	3	4	5	6	7	8	9	10
Lumber	1	2	3	4	5	6	7	8	9	10
Cheese	1	2	3	4	5	6	7	8	9	10
Sunflower Seed	1	2	3	4	5	6	7	8	9	10
Non-fat Dry Milk	1	2	3	4	5	6	7	8	9	10
Onions	1	2	3	4	5	6	7	8	9	10

Thank you for your time.

Buyer Concentration.

The following survey uses the Delphi approach to obtain a cardinal measure of concentration of firms at the pricing points for a given commodity. Some commodities (live cattle for example) have a single pricing point whereas others (wheat, corn etc...) have multiple pricing points. Concentration is defined as the percent of the commodity handled by the largest firms. For commodities with a single pricing point consider only buyer concentration. For commodities with multiple pricing points, concentration should indicate an average concentration across all buyers. A scale of 1 to 10 is used to rate the degree of concentration of the market of a given commodity. A 10 should indicate that the commodity considered has a very concentrated market (small number of firms at all the pricing points), and a one should indicate that the commodity considered does not have a concentrated market (large number of firms at all the pricing points). Please circle the number (only one) that you think, best describes the degree of concentration of the market for the commodities below. In your response please consider only the time period from January 1, 1987 through December 31, 1992.

Buyer Concentration Continued.

Commodity	Scale									
		Lowest								Highest
Soft Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Hard Red Winter Wheat	1	2	3	4	5	6	7	8	9	10
Spring Wheat	1	2	3	4	5	6	7	8	9	10
Corn	1	2	3	4	5	6	7	8	9	10
Feeder Cattle	1	2	3	4	5	6	7	8	9	10
Live Cattle	1	2	3	4	5	6	7	8	9	10
Live Hogs	1	2	3	4	5	6	7	8	9	10
Pork Bellies	1	2	3	4	5	6	7	8	9	10
Soybeans	1	2	3	4	5	6	7	8	9	10
Soybean Meal	1	2	3	4	5	6	7	8	9	10
Soybean Oil	1	2	3	4	5	6	7	8	9	10
Cotton	1	2	3	4	5	6	7	8	9	10
Apples	1	2	3	4	5	6	7	8	9	10
Pears	1	2	3	4	5	6	7	8	9	10
Tomatoes	1	2	3	4	5	6	7	8	9	10
Broilers	1	2	3	4	5	6	7	8	9	10
Eggs	1	2	3	4	5	6	7	8	9	10
Milk	1	2	3	4	5	6	7	8	9	10

Buyer Concentration Continued.

Commodity	Scale									
	Lowest									Highest
Potatoes	1	2	3	4	5	6	7	8	9	10
Rice	1	2	3	4	5	6	7	8	9	10
Orange Juice	1	2	3	4	5	6	7	8	9	10
Lumber	1	2	3	4	5	6	7	8	9	10
Cheese	1	2	3	4	5	6	7	8	9	10
Sunflower Seed	1	2	3	4	5	6	7	8	9	10
Non-fat Dry Milk	1	2	3	4	5	6	7	8	9	10
Onions	1	2	3	4	5	6	7	8	9	10

Thank you for your time.

Final Survey

Grading effectiveness.

The following survey seeks to obtain final rankings. Please consider the means, confidence intervals of the second round and the brief justifications given for estimates outside the confidence intervals. Do you agree with the justifications given? Please state briefly why or why not. Reconsider the ranking of each commodity based on the means, the confidence intervals calculated, and the justifications provided.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Soft Red Winter Wheat	8.17	[6.39-9.94]			
Hard Red Winter Wheat	8.17	[6.39-9.94]			
Spring Wheat	8.17	[6.39-9.94]			
Corn	7.83	[6.37-9.30]			
Feeder Cattle	4.17	[3.48-4.85]			
Live Cattle	4.83	[3.94-5.73]			
Live Hogs	5.67	[4.42-6.91]			
Pork Bellies	7.00	[6.18-7.82]			
Soybeans	7.33	[6.09-8.58]			
Soybean Meal	8.67	[7.72-9.61]			
Soybean Oil	8.50	[7.54-9.46]			
Cotton	7.33	[5.63-9.03]			
Apples	4.00	[2.17-5.83]			

Grading Effectiveness Continued.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Pears	3.83	[1.88-5.78]			
Tomatoes	4.00	[2.47-5.53]			
Broilers	7.83	[6.49-9.18]			
Eggs	7.50	[5.61-9.39]			
Milk	8.00	[6.85-9.15]			
Potatoes	4.67	[3.18-6.16]			
Rice	7.83	[6.94-8.73]			
Orange Juice	6.33	[5.59-7.08]			
Lumber	5.33	[3.36-7.31]			
Cheese	6.83	[4.97-8.70]			
Sunflower Seed	6.83	[4.97-8.70]			
Non-fat Dry Milk	9.33	[8.39-10.28]			
Onions	4.33	[3.59-5.08]			

Thank you for your time.

<u>Brief explanations of extreme rankings</u>:

* Wheat (all wheat)

There is considerable variation in defining grading and testing for quality. Hence a rank of 5 is appropriate.

* Corn

1. Corn grading is as good as wheat. Hence, a rank of 10 is appropriate.

2. There is considerable variation in defining grading and testing for quality. Hence, a rank of 5 is appropriate.

* Live cattle

1. Grading effectiveness is a continuing problem. Hence, a rank of 3 is appropriate.
2. Live cattle grading is more effective than feeder cattle. Hence a rank of 6 is appropriate.

* Soybean meal

1. Grading effectiveness is a continuing problem. Hence, a rank of 3 is appropriate.
2. Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Soybean oil

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Cotton

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Apples

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Pears

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Eggs

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Milk

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

* Sunflower seed

Easy to grade, grades are meaningful, and the system uses the grades. Hence, a rank of 10 is appropriate.

Activeness of Cash Market.

The following survey seeks to obtain final rankings. Please consider the means, confidence intervals of the second round and the brief justifications given for estimates outside the confidence intervals. Do you agree with the justifications given? Please state briefly why or why not. Reconsider the ranking of each commodity based on the means, the confidence intervals calculated, and the justifications provided.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Soft Red Winter Wheat	8.67	[06.87-10.46]			
Hard Red Winter Wheat	8.67	[06.87-10.46]			
Spring Wheat	8.67	[06.87-10.46]			
Corn	8.67	[06.87-10.46]			
Feeder Cattle	6.17	[03.49-08.84]			
Live Cattle	6.33	[04.12-08.54]			
Live Hogs	6.67	[04.11-09.23]			
Pork Bellies	7.33	[05.84-08.82]			
Soybeans	8.83	[07.06-10.61]			
Soybean Meal	7.33	[05.73-08.93]			
Soybean Oil	6.50	[05.12-07.88]			
Cotton	7.50	[05.61-09.39]			
Apples	4.17	[03.27-05.06]			
Pears	3.83	[03.15-04.52]			

Activeness of Cash Market Continued.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Tomatoes	3.83	[02.94-04.73]			
Broilers	1.33	[00.86-01.80]			
Eggs	2.00	[02.00-02.00]			
Milk	3.00	[02.18-03.82]			
Potatoes	3.50	[03.00-04.00]			
Rice	6.00	[04.47-07.53]			
Orange Juice	5.33	[03.84-06.82]			
Lumber	5.50	[04.24-06.76]			
Cheese	3.17	[02.10-04.23]			
Sunflower Seed	3.17	[02.27-04.06]			
Non-fat Dry Milk	3.00	[01.85-04.15]			
Onions	3.50	[02.74-04.26]			

Thank you for your time.

<u>Brief explanations of extreme rankings</u>:

* Wheat (all wheat)

Local market (Indiana) does not have a large number of buyers. Thus a rank of 5 is appropriate.

* Corn

Local market (Indiana) does not have a large number of buyers. Thus a rank of 5 is appropriate.

* Feeder cattle

Quotes are not as frequent as indicated by mean. Hence, a rank of 2 is appropriate.

* Live hogs

Local market (Indiana) does not have a large number of buyers. Thus a rank of 4 is appropriate.

* Pork bellies

Believe that Pork bellies market is very active. Hence, a rank of 9 is appropriate.

* Soybean meal

Local market (Indiana) does not have a large number of buyers. Thus a rank of 4 is appropriate.

* Cotton

Local market (Indiana) does not have a large number of buyers. Thus a rank of 4 is appropriate.

* Cheese

Do not see an active cash market for this commodity. Hence, a rank of 1 is appropriate.

Vertical Integration.

The following survey seeks to obtain final rankings. Please consider the means, confidence intervals of the second round and the brief justifications given for estimates outside the confidence intervals. Do you agree with the justifications given? Please state briefly why or why not. Reconsider the ranking of each commodity based on the means, the confidence intervals calculated, and the justifications provided.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Soft Red Winter Wheat	2.83	[01.77-03.90]			
Hard Red Winter Wheat	2.83	[01.77-03.90]			
Spring Wheat	2.83	[01.77-03.90]			
Corn	2.67	[01.42-03.91]			
Feeder Cattle	3.17	[01.59-04.74]			
Live Cattle	5.17	[04.10-06.23]			
Live Hogs	5.33	[04.09-06.58]			
Pork Bellies	5.00	[03.09-06.91]			
Soybeans	3.00	[01.85-04.15]			
Soybean Meal	3.83	[02.77-04.90]			
Soybean Oil	4.83	[03.16-06.51]			
Cotton	3.17	[02.10-04.23]			
Apples	5.17	[03.82-06.51]			
Pears	4.83	[03.77-05.90]			

Vertical Integration Continued.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Tomatoes	5.00	[03.85-06.15]			
Broilers	9.83	[09.46-10.21]			
Eggs	9.00	[08.00-10.00]			
Milk	6.17	[04.95-07.38]			
Potatoes	4.67	[03.72-05.61]			
Rice	4.83	[04.15-05.52]			
Orange Juice	5.83	[04.94-06.73]			
Lumber	3.83	[03.15-04.52]			
Cheese	4.17	[02.70-05.63]			
Sunflower Seed	4.00	[03.18-04.82]			
Non-fat Dry Milk	4.50	[03.74-05.26]			
Onions	4.17	[03.48-04.85]			

Thank you for your time.

<u>Brief explanations of extreme rankings</u>:

* Corn

Market is not vertically integrated except for a few specialties. Thus a rank of 1 is appropriate.

* Live cattle

Market is becoming increasingly integrated. Thus, a rank of 7 is appropriate.

* Live hogs

1. Market is becoming increasingly integrated. Thus, a rank of 7 is appropriate.

2. Regional (North-East) oligopsony is high, which may not be reflected in national numbers. Thus a rank of 7 is appropriate.

* Pork bellies

Do not believe that Pork bellies market is vertically integrated. Hence, a rank of 1 is appropriate.

* Soybean meal

Market is not vertically integrated. Thus a rank of 2 is appropriate.

* Apples

1. Local market (Utah) is highly integrated. Thus a rank of 7 is appropriate.

2. See only little vertical integration in this market. hence a rank of 3 is appropriate.

* Pears

1. Local market (Utah) is highly integrated. Thus a rank of 6 is appropriate.

2. See only little vertical integration in this market. hence a rank of 3 is appropriate.

* Potatoes

Local market (Utah) is highly integrated. Thus a rank of 6 is appropriate.

* Tomatoes

See only little vertical integration in this market. hence a rank of 3 is appropriate.

* Cheese

Market is not vertically integrated. Hence, a rank of 2 s appropriate.

Buyer Concentration.

The following survey seeks to obtain final rankings. Please consider the means, confidence intervals of the second round and the brief justifications given for estimates outside the confidence intervals. Do you agree with the justifications given? Please state briefly why or why not. Reconsider the ranking of each commodity based on the means, the confidence intervals calculated, and the justifications provided.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Soft Red Winter Wheat	3.50	[02.74-04.26]			
Hard Red Winter Wheat	3.50	[02.74-04.26]			
Spring Wheat	3.50	[02.74-04.26]			
Corn	3.00	[01.59-04.41]			
Feeder Cattle	4.57	[02.13-07.01]			
Live Cattle	6.57	[03.80-09.34]			
Live Hogs	6.43	[03.56-09.30]			
Pork Bellies	4.86	[02.69-07.02]			
Soybeans	3.43	[01.67-05.19]			
Soybean Meal	5.00	[02.80-07.20]			
Soybean Oil	5.00	[02.80-07.20]			
Cotton	6.33	[05.23-07.44]			
Apples	5.67	[04.18-07.16]			
Pears	6.00	[04.59-07.41]			

Buyer Concentration Continued.

Commodity	Mean	Confidence Interval	Your Estimate	Explanation	New Estimate
Tomatoes	5.33	[04.86-05.80]			
Broilers	8.14	[04.74-11.54]			
Eggs	8.33	[07.39-09.28]			
Milk	4.29	[02.38-06.19]			
Potatoes	6.17	[05.48-06.85]			
Rice	5.86	[03.16-08.55]			
Orange Juice	6.50	[06.00-07.00]			
Lumber	6.83	[06.15-07.52]			
Cheese	6.00	[03.49-08.51]			
Sunflower Seed	6.00	[04.85-07.15]			
Non-fat Dry Milk	6.00	[04.17-07.83]			
Onions	5.17	[03.82-06.51]			

Thank you for your time.

<u>Brief explanations of extreme rankings</u>:

* Wheat (all wheat)

Market is quite concentrated in local market (Utah) but not as much nationally. Thus a rank of 4 is appropriate.

* Feeder cattle

1. Buyers are concentrated in local market (Massachusetts). Thus a rank of 7 is appropriate.

2. The market is becoming more concentrated over time, hence a rank of 7 is appropriate.

Panel of experts

Dr. Dennis Henderson (U.S. Department of Agriculture Washington D.C.)

Dr. DeVon Bailey (Utah State University)

Dr. Julie A. Caswell (University of Massachusetts)

Dr. Marvin Hayenga (Iowa State University)

Dr. Paul Farris (Purdue University)

Dr. Richard Rogers (University of Massachusetts)

Dr. Stephen Koontz (Oklahoma State University)

ESSAY TWO

HOW TO BEST PREDICT PRICE AND YIELD RISK WITH RISK MEASURED AS SEMIVARIANCE.

HOW TO BEST PREDICT PRICE AND YIELD RISK WITH RISK MEASURED AS SEMIVARIANCE.

Abstract

Although many alternatives have been suggested, there is no general agreement on which method to use to measure risk. The purpose of this study is to help reach agreement by determining the relative accuracy in predicting price and yield variability (or risk) of three approaches: the first approach uses an empirical distribution function to predict risk. The second approach assumes normality and considers the first two moments. Under this approach, estimates of risk can be biased if distributions are not normal. However, if distributions are normal, this approach is more efficient than the approach based on an empirical distribution function. The third approach incorporates third and fourth moments, since there are no reasons to believe that third and fourth moments are insignificant. If distributions are not normal, this approach is more efficient than an approach that assumes normality. Risk is defined as squared deviations below a target. Root mean square errors and regression analysis were used to compare the alternative methods. Statistical results suggest that one approach is about as good as another which could explain why there is so little agreement about which measure to use.

Key words: Edgeworth expansion, method of moments, normality, price, risk, semivariance, yield.

HOW TO BEST PREDICT PRICE AND YIELD RISK WITH RISK MEASURED AS SEMIVARIANCE.

Introduction

Agriculture is affected by weather, technological innovations, public policies and more. A severe drought reduces crop yield thereby affecting negatively farmers returns. A sudden fall of crop prices also affects negatively farmers. These uncertain events (drought, price fall among others) alter farmers well-being. Following Robinson and Barry, these events can be classified as risky. It follows that uncertain events whose outcomes are non-risky are irrelevant to decision making. Consequently, risk should be measured as downside movement, since downside price variability (for example) alter decision maker's well-being. A measure of risk that has been widely used in the literature is variance (Hurt and Garcia; Lin; Just). Variance is an appropriate measure of risk only if the underlying distribution is location-scale invariant[1] (Meyer). Only little studies have advocated measuring risk as semivariance (Porter and Fishburn). A popular view is that only downside movements should be used as a measure of risk. To the extent that this view is accurate, it casts doubt on measures of risk that include only upside movements, and those that include both upside and downside movements.

Most empirical risk studies are based on expected utility. Pope and Ziemer grouped these studies into two general types. The first type, parametric or "plug-in" approach,

[1]The main distribution which is location-scale invariant is the normal distribution.

assumes a family of probability distributions and compares the moments of that probability distribution. The common assumption is that distributions are normal and that perhaps higher order moments are insignificant (Tsiang). Hence, only the first two moments (mean-variance) are considered. The second type does not require the normality assumption and it makes comparisons based upon empirical probability distributions (Pope and Ziemer). Under the "plug-in" approach, estimates of risk, can be biased if distributions are not normal. However, if distributions are normal the plug-in approach would be more efficient than an approach based on an empirical distribution function. Moreover, there are no reasons to believe that higher order moments will be insignificant. Hence, an approach that incorporates higher order moments would be expected to be preferred to one based on normality when the distribution is not normal. The plug-in approach and the Edgeworth expansion approach are expected to provide better prediction of price and yield risk since in both cases semivariance is calculated in association with a probability distribution. Indeed, as Fishburn (pp. 117) noted,

"... decision makers in investment contexts very frequently associate risk with failure to attain a target return. To the extent that this contention is correct, it casts serious doubt on variance-or, for that matter, on any measure of dispersion taken with respect to a parameter (for example, mean) which changes from distribution to distribution-as a suitable measure of risk."

It follows from Fishburn that unless the probability density function (pdf) underlying the data at hand is location-scale invariant, mean-variance analysis is inappropriate. The purpose of this study is to determine the relative accuracy in predicting risk of three approaches:

method of moments (based on an empirical distribution function), normality (plug-in approach), and an Edgeworth expansion that incorporates third and fourth moments.

In the present research, although risk is defined as squared deviations below a target (i.e. semivariance) and the target is set equal to an expectation, risk is calculated in association with a probability distribution (case of the normal approximation and the Edgeworth expansion). Following Fishburn, Holthausen, and Robinson and Barry it could be argued that utility is "truly " affected by negative deviations (deviations that affect decision makers' well-being). Indeed, Tronstad and McNeil and many mathematical programming studies such as Brink and McCarl, and Hazell argued that farmers or decision makers in general are most responsive to downside price variability.

Semivariance is predicted using each approach (approach based on empirical distribution function, approach based on normality assumption, and approach based on Edgeworth expansion). The different approaches are evaluated on their ability to predict deviations below a target. Varying time lags (five, 10 and 20 years) are considered in order to capture the actual length of the physical production process.

Theory

Historical semivariance is derived in the same manner as mean-variance with the only difference being the substitution of semivariance for variance. Historical semivariance is defined as follows:

(1) $$r(h) = \begin{cases} \frac{1}{T} \sum_{t=1}^{T} (x - \tau)^2 & \forall \quad x < \tau \\ 0 & \forall \quad x \geq \tau \end{cases}$$

where x is the random variable, τ is the reference point (or target), and T is the sample size. Porter showed that the use of semivariance is constistent with maximizing expected utility where the utility function has the form

$$(2) \qquad U(x) = \begin{cases} a + bx + c(x - \tau)^2 & \forall \; x < \tau \\ a + bx & \forall \; x \geq \tau \end{cases},$$

where a, b, and c are constant, b > 0 and c < 0. x and τ are as previously defined. A more general model was developed by Fishburn in which risk is measured as the integral of the product of some given distribution and the dispersion below a target. His model is

$$(3) \qquad \rho(F) = \int_{-\infty}^{\tau} \varphi(\tau - x) dF(x) ,$$

where $\varphi(y)$, for $y \geq 0$, is a nonnegative nondecreasing function of y with $\varphi(0) = 0$, τ is the point of no gain and no loss (target), and $F(x)$ is some given distribution. $F(x)$ is assumed bounded with $F(x_1) = 0$ and $F(x_2) = 1$ for some real x_1 and x_2. Fishburn showed that risk defined by semivariance (as shown in equation (3)) is congruent with the expected utility model, for ranking F and G, in the sense that

$$(4) \qquad U(\mu(F),\ \rho(F)) > U(\mu(G),\ \rho(G))$$

if and only if

$$(5) \qquad \int_{-\infty}^{\infty} u(x)\, dF(x) > \int_{-\infty}^{\infty} u(x)\, dG(x)$$

with U being the expected utility. U is increasing in μ (mean) , decreasing in ρ, and with u(τ)=τ, and u(τ+1)=τ+1, and where for a positive constant k, utility is

(6) $$U(x) = \begin{cases} x & \forall \ x \geq \tau \\ x - k\varphi(\tau - x) & \forall \ x \leq \tau \end{cases}$$

A specific form of equation (3) is the α-τ model which is simpler to estimate (Holthausen). Risk in the α-τ model is defined by

(7) $$r(F) = \int_{-\infty}^{\tau} (\tau - x)^{\alpha} dF(x) \qquad \alpha > 0$$

where α is a measure of the relative impact of large and small deviations. When α = 2, equation (7) is a measure of mean-semivariance. Fishburn also showed that the α-τ model is congruent with the expected utility model where utility function is

(8) $$U(x) = \begin{cases} x & \forall \ x \geq \tau \\ x - k(\tau - x)^{\alpha} & \forall \ x \leq \tau \end{cases}$$

When α = 2, the utility function represents the usual mean-semivariance utility function. But historical semivariance still may not provide the most accurate estimates of expected utility since it is not associated with a probability distribution.

Research Methods

Two sources of risk are considered in the present study: price risk and yield risk. Price and yield expectations are used as the target. Price expectations (P_t^*) are assumed formed from past prices (P_{t-1}). For simplicity, naive expectations are assumed. That is,

$$P_t^* = P_{t-1}. \tag{9}$$

Yield expectations (Y_t^*) are assumed formed from yields over the last five, ten, or 20 years (assumptions are based on the length of the physical production process: how farmers make expectations). Given the length of the data series, a time trend was removed from the yields (Y_t). Analyses were also conducted on cases where time trend was not removed (in the five and 10 year cases). The time trend is removed by taking the predicted values of a regression of yield on *time* over the relevant range as the expected value. When expectations are formed from yields over the last ten years, the first regression is run over the range t to $(t-10)$ to determine yield expectation at time $t+1$ (Y^*_{t+1}). The second regression is run over the range $(t-1)$ to $(t-11)$ to determine yield expectation at time $t-1$ (Y_t^*). That is, a ten year moving data set is used. The regression model is,

$$Y_t = \alpha_0 + \alpha_1 \, time_t + \epsilon_t , \tag{10}$$

and the predicted values are given by

$$Y^*_{t+1} = \hat{\alpha}_0 + \hat{\alpha}_1 \, time_t , \tag{11}$$

where, Y_t = yield at time t, Y^*_{t+1} = yield expectations at time $t+1$ conditional on information available at time t, $\hat{\alpha}_i$ $(i = 0, 1)$ are parameters to be estimated, $time_t$ = time variable (time is set equal to five, 10, and 20 years for the different time lag considered).

Semivariance Versus Total Variance

The difference between semivariance and total variance is that semivariance as defined by Porter is the expected value of squared deviations below a critical (or target) value. Whereas, total variance is the expected value of total squared deviations around the mean. Semivariance for the price data is defined as

(12) $$S = \begin{cases} \frac{1}{T-1} \sum_{t=1}^{T} (P_t - P_t^*)^2 & \forall \quad P_t < P_t^* \\ 0 & \forall \quad P_t \geq P_t^* \end{cases}$$

Semivariance for the yield data is obtained by substituting Y_t for P_t and Y_t^* for P_t^* in equation (12). In what follows, only equations for the price data are written.

Methods for Estimating Semivariance

Method of Moments (historical semivariance)

Semivariance under the method of moments is the easiest to calculate of the three methods considered. If the variables considered are normal, the method of moments is inefficient. However, it is valid if the variables are nonnormal. The method of moments uses historical semivariance and has been widely used in the literature (Brennan; Brink and McCarl; Hazell; and Porter). Under this method, and following Porter, semivariance is

(13) $$S_{mt} = \begin{cases} E[(P_t - E(P_t))^2] & \forall \quad P_t < E(P_t) \\ 0 & \forall \quad P_t \geq E(P_t) \end{cases}$$

where, S_{mt} represents semivariance estimated using the method of moments and $E(.)$ is the expectation symbol.

Normal Approximation

Under the second method, semivariance is approximated by assuming normality. Under the above assumption, a normal probability density function (pdf) of the variables considered (price or yield) is incorporated in the estimation. This method is expected to perform better than the historical semivariance provided that the normality assumption is correct. However, if the variables are not normal, this method may yield biased estimates. Following the definition of risk in the α-τ model, where α is set equal to 2, semivariance is obtained by the following integral:

$$S_{nt} = \int_{-\infty}^{P_t^*} (P_t - P_t^*)^2 f(P_t) dP_t \qquad (14)$$

where S_{nt} represents semivariance estimated assuming normality, and $f(P_t)$ is the normal probability density function. The integral defined in (14) can be calculated to obtained predicted values of price semivariance. The predicted values of yield semivariance when time trend is removed is obtained by substituting $(P_t - P_t^*)^2$ for e_t^2 (e_t is the prediction error) in (14).

Edgeworth Expansion

Under this third method, semivariance is estimated using an approximation to the true distribution of the variable under consideration. This approximation is called Edgeworth expansion. It uses the third and fourth moments (skewness (K_3) and kurtosis (K_4) respectively). The Edgeworth expansion formula derived in Spanos (pp.207) is:

(15)
$$Z_t(P_t) = \begin{cases} \phi(P_t)\ [\ 1 + \frac{1}{\sqrt{T}} K_3 \frac{H_3(P_t)}{3!} \\ + \frac{1}{T} \left\{ K_4 \frac{H_4\,(P_t)}{4!} + 10K_3^2 \frac{H_6(P_t)}{6!} \right\}] + R_{2t} \end{cases}$$

where R_{2t} is the remainder and is a low order of magnitude and can be ignored, T is the number of observations, $\phi(P_t)$ is the standard normal density function of P_t, and $H_m(P_t)$ are the Hermite polynomials of degree m. The first six of these polynomials are (Kendall):

(16)
$$\begin{aligned} H_0 &= 1, \\ H_1 &= P_t, \\ H_2 &= P_t^2 - 1, \\ H_3 &= P_t^3 - 3P_t, \\ H_4 &= P_t^4 - 6P_t^2 + 3, \\ H_5 &= P_t^5 - 10P_t^3 + 15P_t, \\ H_6 &= P_t^6 - 15P_t^4 + 45P_t^2 - 15. \end{aligned}$$

Equation (15) is known as the Edgeworth expansion (Spanos) or more precisely the normal Edgeworth expansion. Using equation (15) we can obtain a prediction of semivariance (S_{ht}) by computing the following integral:

(17)
$$S_{ht} = \int_{-\infty}^{P_t^*} (P_t - P_t^*)^2\ Z_t\ (P_t) dP_t$$

Under normality, skewness and excess kurtosis (K_3, and K_4 in equation (15) respectively) will be zero and equation (17) will be reduced to equation (14). But, this approach (equation (17)) will be inferior to the normal approximation in small samples. Under nonnormality, the Edgeworth expansion is expected to provide more accurate predictions of semivariance than the normal approximation. However, under normality, the Edgeworth expansion should be less efficient than the normal approximation. The integrals defined in (14) and (17) may be computationally cumbersome. For this research, equations (14) and (17) will be evaluated using numerical integration. Quadrature formulas are available to perform numerical integration (Stancu and Stroud; Preckel and DeVuyst). The integrals in (14) and (17) must be transformed before using quadrature formulas. The transformation of (14) and (17) is shown in an appendix. Gaussian quadrature is used to evaluate equations (14) and (17). Twenty six points were considered in the approximation (the number of point was selected arbitrarily).

Model development

So far, we have considered only the different methods of predicting semivariance. The following step is to evaluate the three methods ability to predict semivariance. Root mean square error (RMSE) and bias were computed for each of the methods considered. RMSE was computed as $(\text{bias}^2 + (\text{Std. Dev.})^2)^{0.5}$. RMSE and bias of the different methods were compared to assess the accuracy of the three approaches. A test of paired differences (see Steel and Torrie p.538) was conducted to determine if there was significant difference in the RMSE obtained for each approach. The sign test was used to conducted the test for paired differences (see Sachs and also Steel and Torrie p.538 for details on the sign test).

Then, an "encompassing regression" test was conducted. The test consist of analyzing the relative information content of different prediction methods by means of a regression (Canina and Figlewski; Lamoureux and Lastrapes). The dependent variable (D_t) is the squared negative deviations. Only negative deviations are used because of the initial assumption that only downside movements matter. The independent variables (X_t) are the predicted semivariances obtained from the alternative methods. The general formulation of the regression model is:

$$D_t^* = X'_t\,\beta + \epsilon_t\,, \qquad D_t = \begin{cases} D_t^* & \forall\ D_t^* < 0 \\ 0 & \forall\ D_t^* \geq 0 \end{cases} \tag{18}$$

Equation (18) is a tobit model (Greene; Judge et al.). The residual term ϵ_t is tested for normality using the Shapiro-Wilk test. A significance test for skewness and kurtosis (refers to actual excess kurtosis) is calculated. The following statistics, $T(K^2{}_3/6)$ and $T(K^2{}_4/24)$ can be used to test for skewness and kurtosis respectively (T = number of observations). Under the null hypotheses of zero skewness and zero excess kurtosis, the above statistics are distributed as chi-square with one degree of freedom (Davidson and MacKinnon). Nonnormality is a difficult problem in the tobit model. If disturbances are not normally distributed, the usual estimator is inconsistent (Greene). Research is ongoing on alternative estimators. One way to approach the estimation is to assume alternative distributions in the estimation process. Competing distributions include the exponential, lognormal, loglogistic, and the Weibull distribution. The Kolmogorov-Smirnov (henceforth, KS) test (See Bain and Englehardt for detail on the procedures) is used to test the null hypothesis of an exponential distribution. Because of the computational complexity of the log-logistic and Weibull distribution, a KS test is not conducted for them. However, parameter estimates of the tobit model under both distributions are estimated when normality is rejected.

Orthodox nonnested hypothesis test procedure

Wald version of the nonnested hypothesis test, known as the orthodox test is used to determine the relative accuracy of the alternative methods used to predict semivariance (See Pesaran for more details). The different hypotheses are given below:

(19) $$H_1 : D_t^* = \begin{cases} \alpha_0 + \alpha_1 S_{mt} + \epsilon_t & \forall D_t^* < 0 \\ 0 & \forall D_t^* \geq 0 \end{cases}$$

(20) $$H_2 : D_t^* = \begin{cases} \eta_0 + \eta_1 S_{nt} + \epsilon_t & \forall D_t^* < 0 \\ 0 & \forall D_t^* \geq 0 \end{cases}$$

(21) $$H_3 : D_t^* = \begin{cases} \delta_0 + \delta_1 S_{ht} + \epsilon_t & \forall D_t^* < 0 \\ 0 & \forall D_t^* \geq 0 \end{cases}$$

where α, δ, and η are parameters to be estimated. Under H_1 (equation 19), semivariance is predicted using the method of moments. Under H_2(equation 20), semivariance is predicted using a normal approximation, and under H_3(equation (21), semivariance is predicted using the Edgeworth approximation. The orthodox nonnested hypothesis test consists of artificially nesting the different alternative models into one, and performing joint hypothesis tests on restrictions of the estimated coefficients. The artificially nested model is:

(22) $$H_4 : D_t^* = \begin{cases} \gamma_0 + \gamma_1 S_{mt} + \gamma_2 S_{nt} + \gamma_3 S_{ht} + \epsilon_t & \forall \quad D_t^* < 0 \\ 0 & \forall \quad D_t^* \geq 0 \end{cases}$$

Hypothesis 1 (H_1) tests jointly the restrictions that both parameters γ_2 and γ_3 are zero. In other words, we are testing the hypothesis that semivariance is best predicted by the method of moments. Hypothesis 2 (H_2) tests the hypothesis that semivariance is best predicted by a normal approximation (i.e. γ_1 and γ_3 are zero). Hypothesis 3 (H_3) tests the hypothesis that semivariance is best predicted by the Edgeworth expansion (i.e. γ_1 and γ_2 are zero).

Data and Estimation Procedures

Annual data were used for the present research. Data were obtained from various issues of Agricultural Statistics. The data were collected for the period from 1900 to 1992, and include U.S. prices for wheat (all wheat), corn, soybeans[2], oats, beef cattle[3], and yields for wheat, corn, soybeans, and oats. Descriptive statistics of deviations[4] around a target for prices and yields, and the Shapiro-Wilk, W statistic were computed. Equation (18) was estimated with maximum likelihood using SAS. The analysis was also conducted for a shorter time period (1950 to 1992) to investigate the fragility of results obtained. Results of

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[2]Data for soybeans started in 1924

[3]Average price per 100 pounds of beef cattle, sold out of first hands for slaughter. prices are for prime and choice beef cattle. Data cover period 1925 to 1992.

[4]For price data, total deviations are obtained by taking the difference between the first difference of the log of price and the target price (here target is set equal to the mean). For yield data, total deviations are obtained by taking the difference between actual yield and the target yield (here, target yield is obtained through expectations formed over the past years).

which were commented but not reported here.

Results

Results of the present research are summarized in tables 1 through 8. Tables 1, 2, and 3 present descriptive statistics, skewness, kurtosis, and normality tests for wheat, corn, soybeans, oats, and beef cattle for the different time periods considered. The test statistics computed suggest that deviations around the mean for corn prices and yields are not normally distributed. The hypothesis of normality was also rejected for soybean prices and yields when expectations were formed from yields over the last five years; and for wheat prices under the 10 and 20 year scenario. In those cases where normality was rejected, the KS test was used to test the null hypothesis of an exponential distribution. As results show in tables 1, 2, and 3, the hypothesis of an exponential distribution was rejected. Hence, under non-normality the remaining two alternative distributions (namely, log-logistic and Weibull) were assumed in estimating the tobit model.

Tables 4, 5, 6, 7, and 8 present RMSE and bias in predicting expected semivariance of yields and prices. When time trend is removed and yield expectations are formed from yields over the last five years, the RMSE results suggest that the method of moments outperforms both the normal approximation and the Edgeworth expansion in predicting expected semivariance of yields (Table 5). However, neither method dominated others in predicting semivariance of prices and yields in the remaining scenarios (tables 4, 6, 7, and 8). The overall test (test of paired differences) of whether the RMSE for the alternative methods were significantly different suggested that the RMSEs were not significantly different[5].

In addition to the RMSE, regression analysis and nonnested hypothesis tests were conducted. Because none of the parameter estimates were significant, results of the regression analysis and the nonnested hypothesis tests are not reported. However, those results are consistent with results suggested by RMSEs presented above. These results suggest that no method, is superior[6]. Even though it was expected that methods incorporating higher moments such as the Edgeworth expansion would outperform the method of moments, since it incorporates third and fourth moments and also associates a probability distribution, no significant difference is found. Moreover, results presented in this paper suggest that it does not matter which method is used to predict semivariance of yields and prices.

Summary and Conclusions

The purpose of this study was to determine the relative accuracy in predicting price and yield risk of three approaches. Those approaches included: the historical semivariance, the normal approximation, and the Edgeworth expansion. RMSEs were computed for each method. An overall test of the RMSEs, and an orthodox nonnested test were performed.

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[5] The data set used to conduct the test was composed of pooled RMSE in each scenario considered. That is, we have, for example in the case where expectations are formed from yields over the past five years, 13 observations for each method. We then used The sign test to test for
paired differences.

[6] Similar results also not reported here, were obtained when we used a shorter time period (1950 to 1992, instead of 1900 to 1992).

Results of the tests suggested that RMSEs for the alternative methods were not significantly different, and also that results of the nonnested hypothesis test were not significantly different. The RMSEs also suggested that no single method dominates others. This last result was confirmed by the regression analysis, the orthodox nonnested hypothesis test, and using a shorter time period to conduct the same analysis. The statistical results suggest that although utility depends only on deviations below a target, mean-semivariance may still not be the preferred approach. Methods using moments (E-S) are as good as methods that include probability distributions (normal approximation and Edgeworth expansion). The argument that only downside price movements should be included in a risk measure is not correct even when utility is only affected by negative deviations, but such measures do not lead to serious errors.

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Table 1. Descriptive Statistics of the Deviations Around a Target for Prices and Yields, and Normality Tests for Wheat, Corn, Soybeans, Oats, and Beef Cattle when Yield Expectations Are Formed from Yields over the Last Five Years.

Statistics	Wheat	Corn	Soybeans	Oats	Beef Cattle
Prices					
Mean	-0.0038	0.0002	0.0012	-0.0018	0.0013
Variance	0.0672	0.0799	0.0756	0.0809	0.0322
Skewness	0.4029	-0.5888	-0.2854	0.1338	0.2731
	(2.382)	(5.085)[d]	(0.868)	(0.263)	(0.771)
Kurtosis	1.9325	1.4848	2.4072	0.8596	1.2647
	(13.694)[d]	(8.084)[d]	(15.453)[d]	(2.709)	(4.132)
Prob.normal[a]	0.2656	0.0834	0.0402*	0.6914	0.6215
KS Stat[c]			8.2149		
Yields					
Mean	0.0673	0.2345	0.0737	0.1412	
Variance	5.7681	96.7659	7.5125	36.9258	
Skewness	-0.3843	-2.0004	-0.9886	0.2510	
	(2.166)	(58.694)[d]	(10.424)[d]	(0.934)	
Kurtosis	0.8341	9.1115	2.6129	0.5033	
	(2.551)	(304.404)[d]	(18.206)[d]	(0.929)	
Prob.normal[a]	0.1304	0.0001*[b]	0.0364*	0.6629	
KS Stat[c]		7.5200	7.4060		
Observations	88	88	64	88	62

[a] The Shapiro-Wilk statistic, W, was computed to test the hypothesis that the different data were normal.
[b] The asterisks indicate rejection of the normality assumption at the 5% level.
[c] Critical value of the KS statistic at the 5% significance level is 1.094
[d] Rejection of the null hypothesis of zero skewness and zero excess kurtosis at the 5% significance level.

Table 2. Descriptive Statistics of Deviations Around a Target for Prices and Yields, and Normality Tests for Wheat, Corn, Soybeans, Oats, and Beef Cattle when Yield Expectations Are Formed from Yields over the Last Ten Years.

Statistics	Wheat	Corn	Soybeans	Oats	Beef Cattle
Prices					
Mean	-0.0033	-0.0029	0.0074	-0.0043	-0.0023
Variance	0.0541	0.0701	0.0472	0.0715	0.0216
Skewness	0.6976	-0.5950	0.3512	0.1151	-0.1243
	(6.733)[d]	(4.898)[d]	(1.213)	(0.183)	(0.147)
Kurtosis	2.5151	1.0159	1.5589	0.6912	1.0774
	(21.876)[d]	(3.569)	(1.652)	(1.652)	(2.757)
Prob.normal[a]	0.0043*	0.0256*	0.3175	0.8534	0.4416
KS Stat[c]	9.3036	9.2904			
Yields					
Mean	-0.0120	0.9447	0.0797	0.1660	
Variance	6.1182	68.9702	6.0928	29.1461	
Skewness	-0.1460	-1.7767	-0.4562	-0.2403	
	(0.295)	(46.575)[d]	(2.046)	(0.798)	
Kurtosis	0.0672	4.5776	0.0784	1.4679	
	(0.016)	(138.134)[d]	(0.015)	(7.452)[d]	
Prob.normal[a]	0.9073	0.0000*[b]	0.3779	0.8664	
KS Stat[c]		7.4978			
Observations	83	83	59	83	57

[a] The Shapiro-Wilk statistic, W, was computed to test the hypothesis that the different data were normal.

[b] The asterisks indicate rejection of the normality assumption at the 5% level.

[c] Critical value of the KS statistic at the 5% significance level is 1.094

[d] Rejection of the null hypothesis of zero skewness and zero excess kurtosis at the 5% significance level.

Table 3. Descriptive Statistics of the Deviations Around a Target for Prices and Yields, and Normality Tests for Wheat, Corn, Soybeans, Oats, and Beef Cattle when Yield Expectations Are Formed from Yields over the Last 20 Years.

Statistics	Wheat	Corn	Soybeans	Oats	Beef Cattle
Prices:					
Mean	-0.0117	-0.0112	-0.0095	-0.0091	-0.0035
Variance	0.0558	0.0697	0.0326	0.0714	0.0179
Skewness	0.5327	-0.5996	-0.1910	0.1440	0.0932
	(3.453)	(4.374)[d]	(0.298)	(0.252)	(0.068)
Kurtosis	2.2797	0.9154	0.1057	0.6278	1.2078
	(15.807)[d]	(2.549)	(0.023)	(1.199)	(2.857)
Prob.normal[a]	0.0093*	0.0173*	0.3781	0.7122	0.9172
KS Stat[c]	8.7363	8.7248			
Yields:					
Mean	0.1681	0.9447	-0.0365	0.0223	
Variance	5.2078	68.9702	1.3834	25.5587	
Skewness	0.1798	-1.7767	0.0928	-0.6562	
	(0.393)	(38.406)[d]	(0.070)	(5.239)[d]	
Kurtosis	1.3095	4.5776	0.6782	1.2069	
	(5.216)[d]	(63.737)[d]	(0.939)	(4.431)[d]	
Prob.normal[a]	0.6533	0.0000*[b]	0.6616	0.2837	
KS Stat[c]		6.7290			
Observations	73	73	49	73	47

[a] The Shapiro-Wilk statistic, W, was computed to test the hypothesis that the different data were normal.
[b] The asterisks indicate rejection of the normality assumption at the 5% level.
[c] Critical value of the KS statistic at the 5% significance level is 1.094
[d] Rejection of the null hypothesis of zero skewness and zero excess kurtosis at the 5% significance level.

Table 4. Root Mean Square Error (RMSE) and Bias of Semivariance of Yields and Prices Predicted Using Historical Semivariance, Normal Approximation, and Edgeworth Expansion Methods when Yield Expectations Are Formed from Yields over the Last Five Years without Removing Time Trend.

	Historical Semivariance		Normal Approximation		Edgeworth Expansion	
Commodity	RMSE	Bias	RMSE	Bias	RMSE	Bias
Yields:						
Wheat	3.6618*[a]	-0.1264	10.9729	-1.6368	11.0809	-1.8080
Corn	87.8924	-9.1642	86.5122*	-4.7809	86.7546	-7.1277
Soybeans	4.2226*	-0.8796	16.0596	-3.3067	13.8387	-2.2636
Oats	39.8908*	1.2909	44.7477	-2.2247	44.8461	0.4558
Prices:						
Wheat	0.0810	0.0086	0.0788*	0.0067	0.0796	0.0077
Corn	0.1399	0.0049	0.1392*	0.0092	0.1395	0.0071
Soybeans	0.1363	0.0049	0.1332*	0.0075	0.1344	0.0062
Oats	0.0867	0.0058	0.0868	0.0052	0.0866*	0.0055
Beef Cattle	0.0336*	0.0013	0.0340	0.0011	0.0337	0.0011
Sign test[b]	1.9200				0.6900	

[a] The smallest Root Mean Square Error.

[b] Critical value of the sign test statistic with one degree of freedom at 5% significance is 3.481. Test for the null hypothesis the RMSE for the different methods are not significantly different.

Table 5. Root Mean Square Error (RMSE) and Bias of Semivariance of Yields Predicted Using Historical Semivariance, Normal Approximation, and Edgeworth Expansion Methods when Yield Expectations Are Formed from Yields over the Last Five Years and Time Trend Removed.

	Historical Semivariance		Normal Approximation		Edgeworth Expansion	
Commodity	RMSE	Bias	RMSE	Bias	RMSE	Bias
Yields:						
Wheat	8.2134*[a]	1.9838	8.2327	0.6618	8.2657	0.6951
Corn	309.6309*	35.2203	311.0731	17.4814	314.0078	12.3256
Soybeans	15.3916*	2.3748	15.4212	0.8404	15.6279	0.5552
Oats	41.8166*	8.0106	41.9899	-0.2118	42.9773	-0.4090

[a] The smallest Root Mean Square Error.

Table 6. Root Mean Square Error (RMSE) and Bias of Semivariance of Yields and Prices Predicted Using Historical Semivariance, Normal Approximation, and Edgeworth Expansion Methods when Yield Expectations Are Formed from Yields over the Last Ten Years without Removing Time Trend.

	Historical Semivariance		Normal Approximation		Edgeworth Expansion	
Commodity	RMSE	Bias	RMSE	Bias	RMSE	Bias
Yields:						
Wheat	2.9639*[a]	-1.1319	3.1724	-1.3444	3.0894	-1.2896
Corn	63.7351	-16.2424	62.7736*	-14.9145*	62.8243	-15.4849
Soybeans	2.8465*	-1.6323	6.0684	-2.7635	5.6831	-2.6756
Oats	36.7141	-0.5378	36.2505*	0.3188	36.3738	0.0521
Prices:						
Wheat	0.0579	0.0002	0.0573*	-0.0018	0.0573	-0.0010
Corn	0.1150	0.0016	0.1136*	0.0066	0.1139	0.0050
Soybeans	0.0630	-0.0132	0.0602*	-0.0104	0.0612	-0.0115
Oats	0.0819	0.0040	0.0818*	0.0036	0.0818	0.0037
Beef Cattle	0.0301	-0.0019	0.0301	-0.0025	0.0301	-0.0023
Sign test[b]	0.6900			0.6900		

[a] The smallest Root Mean Square Error.

[b] Critical value of the sign test statistic with one degree of freedom at 5% significance is 3.481. Test for the null hypothesis the RMSE for the different methods are not significantly different.

Table 7. Root Mean Square Error (RMSE) and Bias of Semivariance of Yields Predicted Using Historical Semivariance, Normal Approximation, and Edgeworth Expansion Methods when Yield Expectations Are Formed from Yields over the Last Ten Years and Time Trend Removed.

	Historical Semivariance		Normal Approximation		Edgeworth Expansion	
Commodity	RMSE	Bias	RMSE	Bias	RMSE	Bias
Yields:						
Wheat	7.7100	1.9206	7.6046*[a]	1.1170	7.6218	1.1647
Corn	177.7707*	23.8150	214.7429	17.5078	208.8429	16.6999
Soybeans	7.9174*	1.2314	8.0021	0.6840	7.9674	0.5846
Oats	46.5210	6.3928	46.1671*	3.3924	46.3716	3.1979

[a] The smallest Root Mean Square Error.

Table 8. Root Mean Square Error (RMSE) and Bias of Semivariance of Yields and Prices Predicted Using Historical Semivariance, Normal Approximation, and Edgeworth Expansion Methods when Yield Expectations Are Formed from Yields over the Last 20 Years and Time Trend Removed.

	Historical Semivariance		Normal Approximation		Edgeworth Expansion	
Commodity	RMSE	Bias	RMSE	Bias	RMSE	Bias
Yields:						
Wheat	5.6546*[a]	0.8248	5.7200	0.0725	5.7000	0.1551
Corn	160.3600*	23.8150	171.9830	17.5079	171.5114	16.6999*
Soybeans	1.6183	1.1181	1.5746	1.4599	1.5714*	1.4152
Oats	43.8037*	6.0141	44.7310	3.7545	45.0872	3.3936
Prices:						
Wheat	0.0659	0.0027	0.0650*	0.0004	0.0651	0.0011
Corn	0.1122	0.0029	0.1113*	0.0005	0.1116	0.0008
Soybeans	0.0488	-0.0097	0.0464*	-0.0074	0.0470	-0.0081
Oats	0.0821*	0.0048	0.0822	0.0039	0.0822	0.0042
Beef Cattle	0.0219	-0.0032	0.0219	-0.0031	0.0219	-0.0031*
Sign test[b]	0.1100			0.1100		

[a] The smallest Root Mean Square Error.

[b] Critical value of the sign test statistic with one degree of freedom at 5% significance is 3.481. Test for the null hypothesis the RMSE for the different methods are not significantly different.

Appendix

The integrals defined in equations (14) and (17) were transformed using Gaussian quadrature approximation. The idea is that, given a definite integral, say, I, with

A1 $$I = \int_{-1}^{1} \psi(q)dq$$

using Gaussian quadrature, we can approximate I to the following summation:

A2 $$I = \sum_{j=1}^{N} \psi(q_j) * A_j$$

where, A_js are quadrature points. We need to transform equation (17) into a form similar to I. This is done by variable transformation. Let rewrite equation (17):

A3 $$S_{ht} = \int_{-\infty}^{P_t^*} (P_t - P_t^*)^2 Z_t(P_t) dP_t$$

with

A4 $$P_t \sim (\bar{P}_t \ , \ \sigma_t)$$

Let

A5 $$w_t = \frac{P_t - \bar{P}_t}{\sigma_t} \sim N(0 \ , \ 1)$$

and

A6 $$w^*_t = \frac{P^*_t - \bar{P}_t}{\sigma_t}$$

solving the above equation for P_t leads to:

A7 $$P_t = \sigma_t w_t + \bar{P}_t$$

Taking the derivative with respect to w_t leads to:

A8 $$dP_t = \sigma_t dw_t$$

Substitute P_t and dP_t by their expressions into S_{ht} to get:

A9 $$S_{ht} = \int_{-\infty}^{w^*_t} (\sigma_t w_t + \bar{P}_t - P^*_t)^2 Z(\sigma_t w_t + \bar{P}_t)\sigma_t dw_t$$

Let

A10 $$q = 2e^{w_t - w^*_t} - 1$$

when $w_t \rightarrow -\infty$, $q \rightarrow -1$

and when $w_t \rightarrow w^*_t$, $q \rightarrow 1$, solve equation (A10) for w_t:

A11 $$w_t = \ln(q + 1) - \ln(2) + w^*_t$$

the derivative of w_t with respect to q is:

A12 $$dw_t = \frac{dq}{(q + 1)}$$

Now, substitute w_t and dw_t into S_{ht}, to get:

A13 $$S_{ht} = \int_{-1}^{1} [\sigma_t(\ln(q + 1) - \ln(2) + w^*_t) + \bar{P}_t - P^*_t]^2 * \\ Z(\sigma_t(\ln(q + 1) - \ln(2) + w^*_t) + \bar{P}_t)\sigma_t(q + 1)^{-1}dq$$

replacing w^*_t by its expression and letting

A14 $$M = \sigma_t(\ln(q + 1) - \ln(2)) + P^*_t$$

we can rewrite equation (A13) as:

A15 $$S_{ht} = \int_{-1}^{1} (q + 1)^{-1} (\sigma_t(\ln(q + 1) - \ln(2)))^2 Z(M)dq$$

where,

A16 $$Z(M) = \Phi(M)\left[1 + \frac{K_3}{\sqrt{t}}\frac{H_3(M)}{3!} + \frac{1}{T}\left\{\frac{K_4}{4!}H_4(M) + 10\frac{K^2{}_3}{6!}H_6(M)\right\}\right]$$

and

A17 $$\phi(M) = \frac{1}{\sqrt{(2\pi)}} e^{-\frac{1}{2}M^2}$$

H(M) are the hermite polynomials. Using the quadrature formula, the approximation can be written as:

A18 $$S_{ht} = \int_{-1}^{1} \psi(q)dq = \sum_{j=1}^{N} \psi(q_j)*A_j$$

where,

A19 $$\psi(q) = (q + 1)^{-1}[\sigma_t(\ln(q + 1) - \ln(2))]^2*Z(M)$$

ESSAY THREE

GARCH OPTION PRICING WITH IMPLIED VOLATILITY

GARCH OPTION PRICING WITH IMPLIED VOLATILITY

Abstract

Generalized autoregressive conditional heteroskedasticity (GARCH) provides a better fit to futures price data than the common assumption of an identical independent normal distribution. GARCH option pricing models (OPM) with historical volatility have proven superior to the log-normality assumption of the Black option pricing model with historical volatility. Implied volatilities derived from GARCH OPM might therefore be expected to provide better guidance in investment decisions than those derived from the Black option pricing model. This paper estimates implied volatilities from GARCH OPM. The estimated implied volatilities are used to forecast option premia. Results are compared against forecasts of option premia using implied volatilities from Black's option pricing model. The GARCH implied volatilities are more stable than the Black implied volatilities. Mean squared errors were computed to assess the forecasting performance of both the Black and the GARCH OPM with implied volatilities. The results suggest from that the GARCH OPM with implied volatility should provide better guidance to market makers and arbitragers than the Black option pricing model with implied volatility for options ranging from 6 to 16 days to maturity. For options ranging from 21 to 50 days to maturity the Black OPM with implied volatility should provide better guidance to market makers and arbitragers than the GARCH OPM with implied volatility would.

Key words: GARCH, implied volatility, Monte Carlo, option pricing model, unconditional volatility.

GARCH OPTION PRICING WITH IMPLIED VOLATILITY

Introduction

Black's option pricing model (OPM) is the dominant model of pricing options on futures contracts. Of the five variables in the Black model, only the standard deviation of returns is not observable, so it is calculated given actual premiums. A standard deviation calculated in this fashion is called an implied volatility. Market makers then use implied volatilities from the previous day to guide their trading as the futures price changes. Hauser and Liu found that a Black option pricing model with implied volatility is superior, in predicting actual option prices, to a Black option pricing model with a volatility estimated from historical data. Among models of historical data, generalized autoregressive conditional heteroskedasticity (GARCH) models have proven superior to the log-normality assumption of the Black model (Yang and Brorsen). A GARCH OPM with historical volatility has proven superior to the Black model with historical volatility (Myers and Hanson; Kang and Brorsen). Indeed, it is now evident that commodity futures prices exhibit time varying volatility and tend to have excess kurtosis (characteristics that are not taken into account by the log-normality assumption of the Black model). A GARCH model with a conditional student *t* distributions can capture both the time-varying volatility and the excess kurtosis (Yang and Brorsen). The GARCH models with historical volatility are still inferior to a Black model with implied volatility.

The purpose of this study is to determine whether a GARCH option pricing model with implied volatility provides a more accurate forecast of option premia than the Black model with implied volatility. Engle and Mustafa and Hanson, Myers, and Wang derive implied GARCH parameters from option premia, however, they estimated all the parameters of the GARCH model except historical volatility. The present paper proposes an alternative approach. The alternative is to estimate the GARCH parameters on lagged variance (β) and lagged error (α) from historical data. Unconditional volatility will then be estimated given the GARCH parameters by minimizing squared errors. Since estimates of α and β are relatively constant across studies this approach may improve forecast error since there will be two less parameters to estimate and there are often only six observations available. Unconditional volatility changes due to seasonality in variance among other factors. Initial volatility must be calculated in an arbitrary fashion when it is calculated from historical data. In the present research, initial volatility was set equal to the 20 day historical volatility. Implied volatilities with GARCH will be compared to implied volatilities estimated using Black's option pricing model. Moreover, implied volatilities from both GARCH and Black option models will be used to simulate actual market option prices. The performance of each model will then be determined.

Background

To estimate the implied GARCH parameters, Engle and Mustafa solved the following minimization problem:

$$\min \sum_{j=1}^{J} \theta_j \, [P_{jt} - \hat{P}_{jt}(\omega_t, \alpha_t, \beta_t; \hat{h}^2_{t-1})]^2 \tag{1}$$

where, θ_j represent relative weights and the j subscript indicates put and call options written on the same underlying futures contract but with different strike prices. For simplicity, they assumed equal weights. The symbols α_t, ω_t, and β represent the implied GARCH parameters, P_{jt} represent the actual premiums. The estimated option premium $\hat{P}_{jt}$ is a function of the GARCH parameters conditional on historical volatility ($\hat{h}^2_{t-1}$). The choice variables in the problem described in equation (1) are the GARCH parameters α, ω, and β. The approach we propose is

(2) $$\min \sum_{j=1}^{J} \theta_j \, [P_{jt} - \hat{P}_{jt}(\sigma^2{}_t; \, \hat{\alpha}, \, \hat{\beta}, \, \hat{h}^2_{t-1} \,) \,]^2$$

here, we assume that $\theta_j = 1$. The estimated option premium $\hat{P}_{jt}$ conditional on the GARCH parameters ($\hat{\alpha}$ and $\hat{\beta}$) and the initial volatility ($\hat{h}^2_{t-1}$), is a function of the unconditional volatility σ^2_t. The choice variable in equation (2) is σ^2_t, since ($\hat{\alpha}$ and $\hat{\beta}$) are constant across studies and initial volatility is set equal to the 20 day historical volatility. The variable to be estimated is obtained as follows:

(3) $$\sigma_t^2 = \frac{\omega_t}{(1 - \hat{\alpha} - \hat{\beta})}$$

Procedures

GARCH with a conditional *t* distribution (henceforth GARCH-t) was estimated by maximum likelihood using the first differences of the natural logarithms of the daily closing prices of wheat at the Chicago Board of Trade. The first differences were re-scaled by multiplying them by 100.

The GARCH-t process was defined to model well-documented market anomalies such as day-of-the-week effects in both the mean and variance equation (Chiang and Tapley; Junkus), seasonality in variance (Anderson; Kenyon et al.), and maturity in variance (Milonas). The general stochastic process can be written as follows:

(4) $$y_t = \mu + \epsilon_t$$

where $y_t = 100(\ln(P_t) - \ln(P_{t-1}))$, P_t is Chicago wheat futures price, and

(5) $$\epsilon_t \sim (\frac{v-2}{v})^{1/2} w_t h_t$$

where w_t is i.i.d student with degree of freedom v, $E(w_t) = 0$ and $Var(w_t) = v/(v-2)$, and h_t^2 is the time varying variance of ϵ_t. h^2_t is expressed as:

(6) $$h_t^2 = \omega + \alpha\epsilon_{t-1}^2 + \beta h_{t-1}^2$$

In the approach proposed, h^2_{t-1} is the initial volatility, and the unconditional volatility is σ^2_t. Since, initial volatility is not a choice variable, only a restricted version of equation (6) was used in estimating implied volatilities and simulating option premia. The mean and variance equations estimated are respectively:

(7) $$y_t = a_0 + a_1 D_{MON_t} + a_2 D_{TUE_t} + a_3 D_{WED_t} + a_4 D_{THU_t} + \epsilon_t$$

(8) $$\begin{aligned} h_t^2 = {} & \omega + \alpha\epsilon_{t-1}^2 + \beta h_{t-1}^2 + b_1 D_{MON_t} + b_2 D_{TUE_t} + b_3 D_{WED_t} \\ & + b_4 D_{THU_t} + b_5 \sin(2\pi K_t/252) + b_6 \cos(2\pi K_t/252) \\ & + b_7 \sin(2\pi K_t/126) + b_8 \cos(2\pi K_t/126) + b_9 MATURITY_t \end{aligned}$$

where D denotes dummy variable for each day of the week; thus, $D_{MON} = 1$ if Monday and 0 otherwise, $D_{TUE} = 1$ if Tuesday and 0 otherwise, $D_{WED} = 1$ if Wednesday and 0 otherwise, and $D_{THU} = 1$ if Thursday and 0 otherwise. The constant π is approximated as 3.14, and K_t in the sine and cosine functions is the number of trading days after January 1 of the particular year. Denominators in the sine and cosine functions are the specified cycle length in trading days, that is, 252 indicates a one-year cycle whereas 126 indicates a half-year cycle. $MATURITY_t$ denotes the time to maturity measured as the number of trading days prior to maturity. The GARCH-t process was estimated using the maximum likelihood module of the statistical software package GAUSS. The Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm was used in the estimation.

Parameter estimates of the GARCH-t process (used as starting values), market determined option premia, and initial futures prices are required to solve equation (2). Since the GARCH option pricing model does not have a closed form solution, a Monte Carlo approach (see Paskov for details on Monte Carlo algorithm) was used to approximate option premia, defined as $\hat{P}_{jt}$ in equation (2), which is then discounted back at the risk-free interest rate. The discount factor being:

(9) $$d = e^{-rT}$$

where r is the risk-free rate of interest and T is the time to maturity. Two sets of random numbers were generated[1]: one from a t-distribution with v degrees of freedom and another from a standard normal distribution. Time was measured in number of trading days. The

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[1] The random numbers are generated using the same seed (seed = 409473).

time-varying conditional variances were generated for T periods using parameter estimates from the GARCH. Then, with the conditional variances, the futures prices F_t are simulated for T periods to get the futures price at maturity. Denoting this price at maturity F_{it}, the simulated option premia are:

$$\hat{P}_{jt} = \begin{cases} d(1/n)\sum_{i=1}^{n} \max[k - F_{it}, 0] & \forall \; call, \\ d(1/n)\sum_{i=1}^{n} \max[F_{it} - k, 0] & \forall \; put, \end{cases} \tag{10}$$

where n = 1000 is the number of replications of this procedure, and k is the strike (or exercise) price of the option. The optimization in (2) was then solved using the OPTMUM module of GAUSS. Since GARCH processes account for both time-varying volatility and excess kurtosis, GARCH implied volatilities are expected to be more stable than those obtained using the Black option pricing model. The Broyden-Fletcher-Goldfarb-Shanno (BFGS) algorithm was used and then switched to the Scaled BFGS algorithm after the 10th iteration. The line search method used was the cubic or quadratic method (known as STEPBT). Implied volatilities were also obtained from the Black option pricing model. A single implied volatility is calculated for each day. In practice, sometimes a different implied volatility is calculated for each strike price.

Black vs GARCH OPM

To examine the ability of the GARCH OPM with implied volatility and Black OPM with implied volatility to forecast actual option premia, implied volatilities resulting from the minimization problem, in the Monte Carlo approach defined earlier, were used to forecast next day Chicago wheat option premiums for given strike prices. Mean squared errors were used to measure the forecasting performance of both GARCH and Black option pricing models. Mean squared errors (MSE) is defined as

$$MSE = \frac{\sum_{t=1}^{T} (AP_t - SP_t)^2}{T} \tag{11}$$

where AP_t is actual Chicago wheat option premia, SP_t is simulated Chicago wheat option. The sign test was used to test whether the mean squared errors from the two option pricing models were significantly different (see Steel and Torrie p. 538 for details on the sign test). The sign test was calculated using the out, at, and in-the-money MSEs for both put and call options. A total of six observations were available to conduct the test. The sign test has a chi-squared distribution with one degree of freedom under the null hypothesis that the mean squared errors from both models are not different.

Data

The data used to estimate the GARCH model were from July 1987 to July 1993, and were created using Continuous Contractor from Technical Tools. The rollover date is the 15th day of the month prior to delivery. Futures options premia were collected from the Wall Street Journal. Indeed, on March 28 1994, closing option premia for six strike prices were quoted on the Chicago Board of Trade for July 1994 futures contracts providing six closing option premia (March 28, 1994 was chosen to be about two months before the option expired). Daily Chicago wheat option premia (both put and call options were considered) and futures prices were collected from the Wall Street Journal from March 28 till the maturity date of the July options contract (June 17 1994). Only options near maturity were considered to minimize problems with non-synchronous trading. The risk free rate of interest was assumed constant throughout the simulation period at r = 3.71%[2]. Descriptive statistics of the log differences of Chicago wheat futures prices are summarized in table 1. Skewness, kurtosis, and the D'Agostino omnibus test[3] provide evidence of non-normality. Chicago wheat futures prices and log differences are plotted in figures 1 and 2. Both figures show that Chicago futures prices have stable and volatile periods. The most volatile periods were the spring of 1988 and the fall of 1991.

Table 1 summarizes descriptive statistics and tests for departures from normality. All three tests show strong support for non-normality. Indeed, they (the tests) reject the null hypotheses of zero skewness and zero excess kurtosis at the 5% significance level. Table 2

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[2]The risk-free rate of return is approximated to be the rate of return on treasury bills with the same maturity date as the option premia collected. Both rate of return on treasury bills and option premia were collected from the Wall Street Journal.

[3] The omnibus test combines both skewness and kurtosis. It is defined as:

$$K^2 = Z^2(\sqrt{b_1}) + Z^2(b2) \sim \chi^2_2$$

where $\sqrt{b_1}$ and b_2 are skewness and kurtosis respectively, and $Z(\sqrt{b_1})$ and $Z(b_2)$ are approximately standard normal with mean zero and variance one. K^2 is distributed as chi-squared with two degrees of freedom under the null hypotheses of zero skewness ($\sqrt{b_1}$ = 0) and zero excess kurtosis ($b_2 - 3 = 0$).

summarizes the actual Chicago wheat futures option premia, and futures prices.

Empirical Results

Table 3 presents parameter estimates of the GARCH-t(1,1) process, test statistics of the null hypotheses of no day-of-the-week effects in both mean and variance equations, and test statistics of the null hypotheses of seasonality in the variance. The estimated GARCH parameters are all significant. The sum of the GARCH terms (α and β) is less than one which implies stationarity. Tests of the significance of day-of-the-week effects show that both mean and variance of Chicago wheat futures price movements differ by day of the week. No significant seasonal pattern is found in the variance. The implied volatilities estimated are plotted in figure 3. The graph shows that GARCH implied volatilities are more stable than Black implied volatilities as hypothesized. Coefficients of variation were also calculated for both implied volatilities. The coefficient of variation of the GARCH implied volatilities is 0.96 whereas that of the Black implied volatilities is 2.152. This result suggests again that GARCH implied volatilities are more stable than the Black implied volatilities. In both cases (GARCH and Black), implied volatilities increase as maturity approaches, results consistent with the findings by Day and Lewis. Indeed, Day and Lewis argued that demand by option traders to close positions in expiring options and to open positions in the next expiration series creates a temporary upward bias in the option prices that is reflected in the estimates of implied volatilities.

Table 5 shows the forecasting performance measured by the mean squared errors of both GARCH and Black option pricing models with initial volatility set equal to the 20 day historical volatility for both put and call premia. The mean squared errors calculated from the actual premia and the simulated GARCH option premia are smaller than those calculated from actual premia and simulated Black option premia at 6 to 15 days to maturity. The sign test result ($6 > 3.84$ the critical value at the 5% significance level) suggests that the mean of the difference of the MSE from the GARCH and the Black is not zero. Moreover, the GARCH OPM with implied volatility outperforms the Black OPM with implied volatility at options close to maturity (6 to 15 days). For options ranging from 16 to 20 days to maturity, the Black OPM with implied volatility is as good as the GARCH OPM with implied volatility as suggested by the sign test result ($0.6667 < 3.84$). For options ranging from 21 to 50 days to maturity, the Black OPM with implied volatility outperforms the GARCH OPM with implied volatility as suggested by the sign test result ($6 > 3.84$).

Summary and Conclusions

This paper estimated implied volatilities with the GARCH option pricing models. The GARCH-t process was used to model Chicago wheat futures price movements. Implied volatilities were found by minimizing squared errors using both GARCH and Black option pricing models. Implied volatilities estimated were then used to simulate actual Chicago wheat option premia. In both GARCH and Black models, implied volatilities estimated increase near maturity. However , the GARCH implied volatilities are more stable than those obtained using the Black option pricing model. Mean squared errors were calculated to assess the forecasting performance of both models. The mean squared errors calculated suggest that the GARCH OPM with implied volatility outperforms the Black OPM with implied volatility at options close to maturity (6 to 15 days). For options ranging from 16 to 20 days to maturity, the Black OPM with implied volatility is as good as the GARCH OPM with implied. For options ranging from 21 to 50 days to maturity, the Black OPM with implied volatility outperforms the GARCH OPM with implied volatility. It results from this research that the GARCH OPM with implied volatility should provide better guidance to market makers and arbitragers than the Black option pricing model with implied volatility for options ranging from 6 to 16 days to maturity. For options ranging from 21 to 50 days to maturity the Black OPM with implied volatility should provide better guidance to market makers and arbitragers than the GARCH OPM with implied volatility would.

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Table 1. Summary Statistics of Daily Chicago Wheat Futures Prices from July 1987 to July 1993[a].

Description	Statistics	Test Value
Sample size	1537	
Mean	0.00608	
Standard Deviation	0.011436	
Skewness	0.181795	2.900[b]
Kurtosis	6.586588	11.564[c]
Omnibus Test		142.140[d]

[a] Units are percentages $([\ln(P_t) - \ln(p_{t-1})]*100$.

[b] statistic has a z distribution under the null hypothesis of zero skewness. The critical value for a two sided test is 1.96 at a 5% significance level.

[c] statistic has a z distribution under the null hypothesis of zero excess kurtosis. The critical value for a two sided test is 1.96 at a 5% significance level.

[d] Chi-square statistic calculated to test the null hypothesis of normality. The critical value at the 5% significance level is 5.99.

Table 2. Chicago Wheat Futures Put Option Premia, March 28, 1994 to June 17, 1994.

	Strike Prices (dollar/bushel)									
Time to Maturity	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	Futures Prices
57	na	0.0400	0.0725	0.1175	0.1775	0.2500	0.3325	na	na	3.2950
56	na	0.0400	0.0750	0.1200	0.1825	0.2550	0.3400	na	na	3.2875
55	na	0.0400	0.0775	0.1250	0.1875	0.2600	0.3425	na	na	3.2825
54	na	0.0550	0.0975	0.1550	0.2225	0.3025	0.3900	na	na	3.2325
53	na	na	0.0800	0.1300	0.1950	0.2700	0.3550	0.4450	na	3.2700
52	na	na	0.0750	0.1200	0.1775	0.2500	0.3325	0.4200	na	3.2975
51	na	na	na	0.0975	0.1413	0.2075	0.2825	0.3675	0.4575	3.3600
50	na	na	na	0.1000	0.1475	0.2150	0.2900	0.3750	0.4650	3.3550
49	na	na	0.0625	0.1050	0.1600	0.2275	0.3100	0.3950	na	3.3300
48	na	0.0475	0.0850	0.1375	0.2025	0.2775	0.3650	na	na	3.2575
47	na	0.0438	0.0825	0.1350	0.1975	0.2750	0.3625	na	na	3.2600
46	na	0.0500	0.0875	0.1450	0.2100	0.2900	0.3775	na	na	3.2400
45	na	0.0700	0.1225	0.1888	0.2638	0.3525	0.4425	na	na	3.1675
44	na	0.0725	0.1263	0.1950	0.2725	0.3575	0.4525	na	na	3.1575
43	na	0.0624	0.1088	0.1738	0.2475	0.3325	0.4250	na	na	3.1875
42	0.0363	0.0750	0.1288	0.1975	0.2788	0.3675	na	na	na	3.1425
41	0.0338	0.0713	0.1213	0.1913	0.2700	0.3575	na	na	na	3.1525
40	0.0325	0.0725	0.1213	0.1975	0.2725	0.3675	na	na	na	3.1425
39	0.0325	0.0700	0.1275	0.1988	0.2788	0.3675	na	na	na	3.1400
38	0.0275	0.0575	0.1050	0.1713	0.2500	0.3350	na	na	na	3.1750
37	0.0225	0.0525	0.0975	0.1625	0.2400	0.3225	na	na	na	3.1900
36	0.0175	0.0363	0.0738	0.1300	0.2000	0.2750	na	na	na	3.2450
35	na	0.0300	0.0538	0.1000	0.1575	0.2275	0.3125	na	na	3.3075
34	na	0.0250	0.0475	0.0900	0.1400	0.2025	0.2825	na	na	3.3475
33	na	0.0300	0.0625	0.1075	0.1675	0.2400	0.3250	na	na	3.3000
32	na	na	0.0488	0.0900	0.1425	0.2050	0.2850	0.3725	na	3.3475
31	na	0.0300	0.0600	0.1075	0.1650	0.2400	0.3225	na	na	3.3025
30	na	0.0363	0.0700	0.1225	0.1850	0.2625	0.3475	na	na	3.2700
29	0.0188	0.0400	0.0750	0.1288	0.1975	0.2725	na	na	na	3.2550
28	0.0200	0.0400	0.0850	0.1475	0.2175	0.3025	na	na	na	3.2175
27	0.0175	0.0388	0.0825	0.1438	0.2150	0.2975	na	na	na	3.2175
26	0.0138	0.0375	0.0800	0.1413	0.2125	0.2950	na	na	na	3.2200
25	0.0138	0.0400	0.0825	0.1413	0.2200	0.3075	na	na	na	3.2050
24	na	0.0275	0.0575	0.1100	0.1750	0.2525	0.3425	na	na	3.2650
23	na	0.0275	0.0600	0.1100	0.1775	0.2675	0.3475	na	na	3.2600

Table 2. Continued.

Time to Maturity	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	Futures Prices
	Strike Prices (dollar/bushel)									
22	0.0125	0.0213	0.0700	0.1275	0.1975	0.2775	na	na	na	3.2400
21	0.0125	0.0325	0.0675	0.1300	0.2025	0.2875	na	na	na	3.2300
20	na	0.0250	0.0550	0.1075	0.1725	0.2550	0.3425	na	na	3.2675
19	na	na	0.0400	0.0788	0.1175	0.1825	0.2600	0.3500	na	3.3675
18	na	0.0225	0.0525	0.0950	0.1525	0.2300	0.3150	na	na	3.2975
17	na	0.0200	0.0500	0.0875	0.1450	0.2200	0.3050	na	na	3.3075
16	0.0125	0.0325	0.0700	0.1375	0.2125	0.2975	na	na	na	3.2175
15	0.0150	0.0388	0.0800	0.1575	0.2350	0.3275	na	na	na	3.1800
14	na	0.0200	0.0475	0.0950	0.1600	0.2400	0.3350	na	na	3.2750
13	na	0.0150	0.0375	0.0850	0.1475	0.2275	0.3175	na	na	3.2900
12	na	0.0113	0.0300	0.0725	0.1325	0.2125	0.3000	na	na	3.3100
11	na	0.0100	0.0300	0.0725	0.1325	0.2125	0.3000	na	na	3.3075
10	na	0.0088	0.0263	0.0638	0.1200	0.2000	0.2900	na	na	3.3175
9	na	na	0.0163	0.0463	0.0963	0.1700	0.2575	0.3500	na	3.3575
8	na	na	0.0100	0.0300	0.0750	0.1425	0.2200	0.3150	na	3.3900
7	na	na	0.0075	0.0350	0.0850	0.1575	0.2463	0.3450	na	3.3575
6	na	na	0.0050	0.0213	0.0575	0.1300	0.2175	0.3125	na	3.3875
5	na	na	0.0038	0.0088	0.0388	0.1050	0.1925	0.2900	na	3.4125
4	na	na	0.0025	0.0113	0.0550	0.1338	0.2263	0.3250	na	3.3750
3	na	na	0.0013	0.0050	0.0350	0.1050	0.1988	0.2950	na	3.4050
2	na	na	0.0013	0.0075	0.0600	0.1500	0.2475	0.3475	na	3.3525
1	na	na	0.0013	0.0013	0.0350	0.1350	0.2350	0.3300	na	3.3525

Note: na = not available.
Source: Wall Street Journal from March 28, 1994 to June 17, 1994.

Table 3. Chicago Wheat Futures Call Option Premia, March 28, 1994 to June 17, 1994 .

	Strike Prices (dollar/bushel)									
Time to Maturity	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	Futures Prices
57	na	0.2325	0.1650	0.1150	0.0725	0.0500	0.0325	na	na	3.2950
56	na	0.2275	0.1600	0.1075	0.0700	0.0475	0.0300	na	na	3.2875
55	na	0.2225	0.1575	0.1063	0.0688	0.0450	0.0275	na	na	3.2825
54	na	0.1850	0.1238	0.0850	0.0550	0.0375	0.0225	na	na	3.2325
53	na	na	0.1475	0.0988	0.0650	0.0450	0.0275	0.0175	na	3.2700
52	na	na	0.1650	0.1175	0.0750	0.0525	0.0350	0.0250	na	3.2975
51	na	na	na	0.1550	0.1000	0.0700	0.0475	0.0325	0.0225	3.3600
50	na	na	na	0.1550	0.1013	0.0725	0.0500	0.0350	0.0250	3.3550
49	na	na	0.1900	0.1350	0.0863	0.0600	0.0425	0.0300	na	3.3300
48	na	0.2000	0.1400	0.0950	0.0588	0.0375	0.0250	na	na	3.2575
47	na	0.2025	0.1400	0.0950	0.0575	0.0375	0.0250	na	na	3.2600
46	na	0.1875	0.1275	0.0850	0.0500	0.0350	0.0225	na	na	3.2400
45	na	0.1375	0.0900	0.0588	0.0350	0.0225	0.0138	na	na	3.1675
44	na	0.1300	0.0850	0.0550	0.0300	0.0200	0.0125	na	na	3.1575
43	na	0.1500	0.0950	0.0638	0.0350	0.0225	0.0138	na	na	3.1875
42	0.1800	0.1175	0.0725	0.0413	0.0225	0.0125	na	na	na	3.1425
41	0.1850	0.1200	0.0750	0.0438	0.0250	0.0150	na	na	na	3.1525
40	0.1775	0.1150	0.0700	0.0400	0.0225	0.0125	na	na	na	3.1425
39	0.1750	0.1100	0.0638	0.0375	0.0213	0.0100	na	na	na	3.1400
38	0.2000	0.1300	0.0800	0.0475	0.0263	0.0138	na	na	na	3.1750
37	0.2125	0.1425	0.0875	0.0525	0.0300	0.0163	na	na	na	3.1900
36	0.2600	0.1800	0.1175	0.0750	0.0450	0.0238	na	na	na	3.2450
35	na	0.2300	0.1600	0.1075	0.0650	0.0400	0.0250	na	na	3.3075
34	na	0.2650	0.1900	0.1338	0.0888	0.0550	0.0338	na	na	3.3475
33	na	0.2300	0.1600	0.1075	0.0688	0.0425	0.0250	na	na	3.3000
32	na	na	0.1938	0.1350	0.0875	0.0550	0.0325	0.0250	na	3.3475
31	na	0.2300	0.1600	0.1100	0.0663	0.0425	0.0275	na	na	3.3025
30	na	0.2050	0.1400	0.0900	0.0550	0.0350	0.0225	na	na	3.2700
29	0.2700	0.1925	0.1225	0.0813	0.0500	0.0313	na	na	na	3.2550
28	0.2350	0.1575	0.1013	0.0625	0.0350	0.0225	na	na	na	3.2175
27	0.2325	0.1525	0.1000	0.0613	0.0325	0.0200	na	na	na	3.2175
26	0.2350	0.1550	0.1000	0.0600	0.0325	0.0175	na	na	na	3.2200
25	0.2200	0.1425	0.0850	0.0500	0.0250	0.0125	na	na	na	3.2050
24	na	0.1900	0.1200	0.0725	0.0388	0.0200	0.0100	na	na	3.2650
23	na	0.1850	0.1113	0.0688	0.0375	0.0188	0.0100	na	na	3.2600

na = not available.

Table 3. Continued.

Time to Maturity	3.00	3.10	3.20	3.30	3.40	3.50	3.60	3.70	3.80	Futures Prices
	Strike Prices (dollar/bushel)									
22	0.2475	0.1675	0.1075	0.0650	0.0313	0.0200	na	na	na	3.2400
21	0.2400	0.1513	0.0950	0.0575	0.0325	0.0200	na	na	na	3.2300
20	na	0.1925	0.1200	0.0750	0.0040	0.0023	0.0010	na	na	3.2675
19	na	na	0.2025	0.1425	0.0900	0.0525	0.0300	0.0213	na	3.3675
18	na	0.2200	0.1475	0.0925	0.0525	0.0300	0.0175	na	na	3.2975
17	na	0.2275	0.1550	0.0925	0.0525	0.0275	0.0150	na	na	3.3075
16	0.2275	0.1500	0.0863	0.0525	0.0250	0.0138	na	na	na	3.2175
15	0.1900	0.1150	0.0600	0.0338	0.0150	0.0075	na	na	na	3.1800
14	na	0.1950	0.1150	0.0675	0.0350	0.0163	0.0100	na	na	3.2750
13	na	0.2050	0.1250	0.0725	0.0375	0.0175	0.0100	na	na	3.2900
12	na	0.2200	0.1400	0.0825	0.0425	0.0225	0.0125	na	na	3.3100
11	na	0.3100	0.2175	0.0800	0.0400	0.0200	0.0100	na	na	3.3075
10	na	0.2250	0.1425	0.0800	0.0388	0.0188	0.0075	na	na	3.3175
9	na	na	0.1688	0.0975	0.0475	0.0275	0.0100	0.0063	na	3.3575
8	na	na	0.2000	0.1200	0.0625	0.0313	0.0125	0.0075	na	3.3900
7	na	na	0.1650	0.0925	0.0400	0.0150	0.0050	0.0038	na	3.3575
6	na	na	0.1925	0.1100	0.0463	0.0175	0.0050	0.0025	na	3.3875
5	na	na	0.2138	0.1225	0.0500	0.0163	0.0050	0.0025	na	3.4125
4	na	na	0.1775	0.0875	0.0300	0.0088	0.0025	0.0013	na	3.3750
3	na	na	0.2063	0.1100	0.0375	0.0100	0.0038	0.0025	na	3.4050
2	na	na	0.1525	0.0600	0.0125	0.0025	0.0013	0.0013	na	3.3525
1	na	na	0.1625	0.0650	0.0050	0.0013	0.0013	0.0013	na	3.3525

Note: na = not available.

Source: Wall Street Journal from March 28, 1994 to June 17, 1994.

Table 4. Parameter Estimates of GARCH-t(1,1) Process of Chicago Wheat Futures Prices

	Estimated Coefficients	p-value[a]		Estimated Coefficients	p-value
Mean:			**Variance:**		
Intercept	-0.024	(0.322)	Intercept	0.052	(0.315)
D_{MON}	0.040	(0.299)	Alpha	0.079*	(0.000)
D_{TUE}	0.062	(0.205)	Beta	0.876*	(0.000)
D_{WED}	0.125*b	(0.037)	D_{MON}	-0.021	(0.450)
D_{THU}	-0.091	(0.097)	D_{TUE}	0.142	(0.155)
			D_{WED}	0.183	(0.109)
			D_{THU}	-0.243	(0.091)
			SIN252	0.013	(0.269)
			COS252	-0.014	(0.097)
			SIN126	-0.005	(0.323)
			COS126	0.002	(0.410)
			MATURITY	-0.011	(0.337)
Degrees of Freedom:					
	7.505	(0.000)*			
Wald F statistics:					
Day of the week in mean					
	2.753*				
Day of the week in Variance					
	2.452*				
Seasonality in Variance					
	0.762				

[a] Numbers in parentheses are probability values. Hence a p-value < 0.05 indicates that the parameter estimated is significant.
[b] Asterisks indicate significance at the 5% level.

Table 5. Forecasting Performance of Black and GARCH-t Option Pricing for 1994 Chicago Wheat July Futures Options with Initial Volatility Set Equal to the 20 Day Historical Volatility.

	Put Options			Call Options		
Moneyness	Out	At	In	Out	At	In
6 to 10 Days to Maturity						
Black						
Mean Errors	0.0125	0.0189	0.0093	0.0114	0.0172	0.0093
Mean Squared Errors	0.0002	0.0004	0.00012	0.0002	0.0003	0.00011
GARCH						
Mean Errors	0.0088*[a]	0.0137*	0.0073*	0.0069*	0.0112*	0.0068*
Mean Squared Errors	0.0001*	0.0002*	0.00008*	0.0001*	0.0001*	0.00006*
Sign Test	6.0000[b]					
11 to 15 Days to Maturity						
Black						
Mean Errors	0.0121	0.0226	0.0133	0.0262	0.0208	0.0136
Mean Squared Errors	0.0002	0.0005	0.0002	0.0018	0.0004	0.0002
GARCH						
Mean Errors	0.0081*	0.0167*	0.0106*	0.0187*	0.0117*	0.0078*
Mean Squared Errors	0.0001*	0.0003*	0.0001*	0.0014*	0.0001*	0.0001*
Sign test	6.0000[b]					
16 to 20 Days to Maturity						
Black						
Mean Errors	0.0166*	0.0276*	0.0177*	0.0153*	0.0258*	0.0142
Mean Squared Errors	0.0003	0.0008*	0.0004	0.0003	0.0007*	0.0004
GARCH						
Mean Errors	0.0172	0.0302	0.0179	0.0160	0.0284	0.0142
Mean Squared Errors	0.0003	0.0009	0.0004	0.0003	0.0008	0.0004
Sign Test	0.6667					

[a] Asterisk indicates smaller mean errors and mean squared errors.

[b] the critical value of the sign test at the 5 % probability level is 3.84.

Table 5. Continued

Moneyness	Put Options Out	Put Options At	Put Options In	Call Options Out	Call Options At	Call Options In
21 to 25 Days to Maturity						
Black						
Mean Errors	0.0056*	0.0119*	0.0123*	0.0038*	0.0082*	0.0112*
Mean Squared Errors	0.0000*	0.0001*	0.0002*	0.0000*	0.0001*	0.0001*
GARCH						
Mean Errors	0.0114	0.0238	0.0180	0.0108	0.0216	0.0183
Mean Squared Errors	0.0002	0.0006	0.0009	0.0001	0.0005	0.0004
Sign test	6.0000[b]					
26 to 30 Days to Maturity						
Black						
Mean Errors	0.0074*	0.0138*	0.0150*	0.0061*	0.0122*	0.0150*
Mean Squared Errors	0.0001*	0.0002*	0.0002*	0.0001*	0.0002*	0.0002*
GARCH						
Mean Errors	0.0151	0.0256	0.0210	0.0147	0.0264	0.0232
Mean Squared Errors	0.0003	0.0007	0.0005	0.0002	0.0007	0.0006
Sign test	6.0000[b]					
31 to 35 Days to Maturity						
Black						
Mean Errors	0.0112*	0.0184*	0.0153*	0.0085*	0.0172*	0.0163*
Mean Squared Errors	0.0001*	0.0004*	0.0002*	0.0001*	0.0003*	0.0003*
GARCH						
Mean Errors	0.0199	0.0327	0.0224	0.0199	0.0346	0.0266
Mean Squared Errors	0.0004	0.0011	0.0006	0.0004	0.0012	0.0007
Sign test	6.0000[b]					

[a] Asterisk indicates smaller mean errors and mean squared errors.
[b] the critical value of the sign test at the 5 % probability level is 3.84.

Table 5. Continued

Moneyness	Put Options Out	Put Options At	Put Options In	Call Options Out	Call Options At	Call Options In
36 to 40 Days to Maturity						
Black						
Mean Errors	-0.0020*	-0.0005*	0.0033*	-0.0016*	-0.0004*	0.0039*
Mean Squared Errors	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
GARCH						
Mean Errors	0.0166	0.0236	0.0149	0.0207	0.0274	0.0192
Mean Squared Errors	0.0003	0.0006	0.0003	0.0004	0.0008	0.0004
Sign test	6.0000[b]					
41 to 45 Days to Maturity						
Black						
Mean Errors	-0.0007*	0.0021*	0.0055*	-0.0007*	0.0024*	0.0061*
Mean Squared Errors	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*	0.0000*
GARCH						
Mean Errors	0.0225	0.0278	0.0154	0.0253	0.0311	0.0190
Mean Squared Errors	0.0005	0.0008	0.0003	0.0007	0.0010	0.0004
Sign test	6.0000[b]					
46 to 50 Days to Maturity						
Black						
Mean Errors	0.0038*	0.0091*	0.0102*	0.0022*	0.0090*	0.0108*
Mean Squared Errors	0.0000*	0.0001*	0.0001*	0.0000*	0.0001*	0.0001*
GARCH						
Mean Errors	0.0309	0.0403	0.0248	0.0367	0.0491	0.0348
Mean Squared Errors	0.0010	0.0016	0.0007	0.0014	0.0025	0.0013
Sign test	6.0000[b]					

[a] Asterisk indicates smaller mean errors and mean squared errors.
[b] the critical value of the sign test at the 5 % probability level is 3.84.

Figure 1. Estimated GARCH-t, Black Implied Volatilities for Chicago Wheat July Futures Contract and the Chicago Wheat Futures' 20 Day Historical Volatilities from March 28, 1994 to June 17, 1994

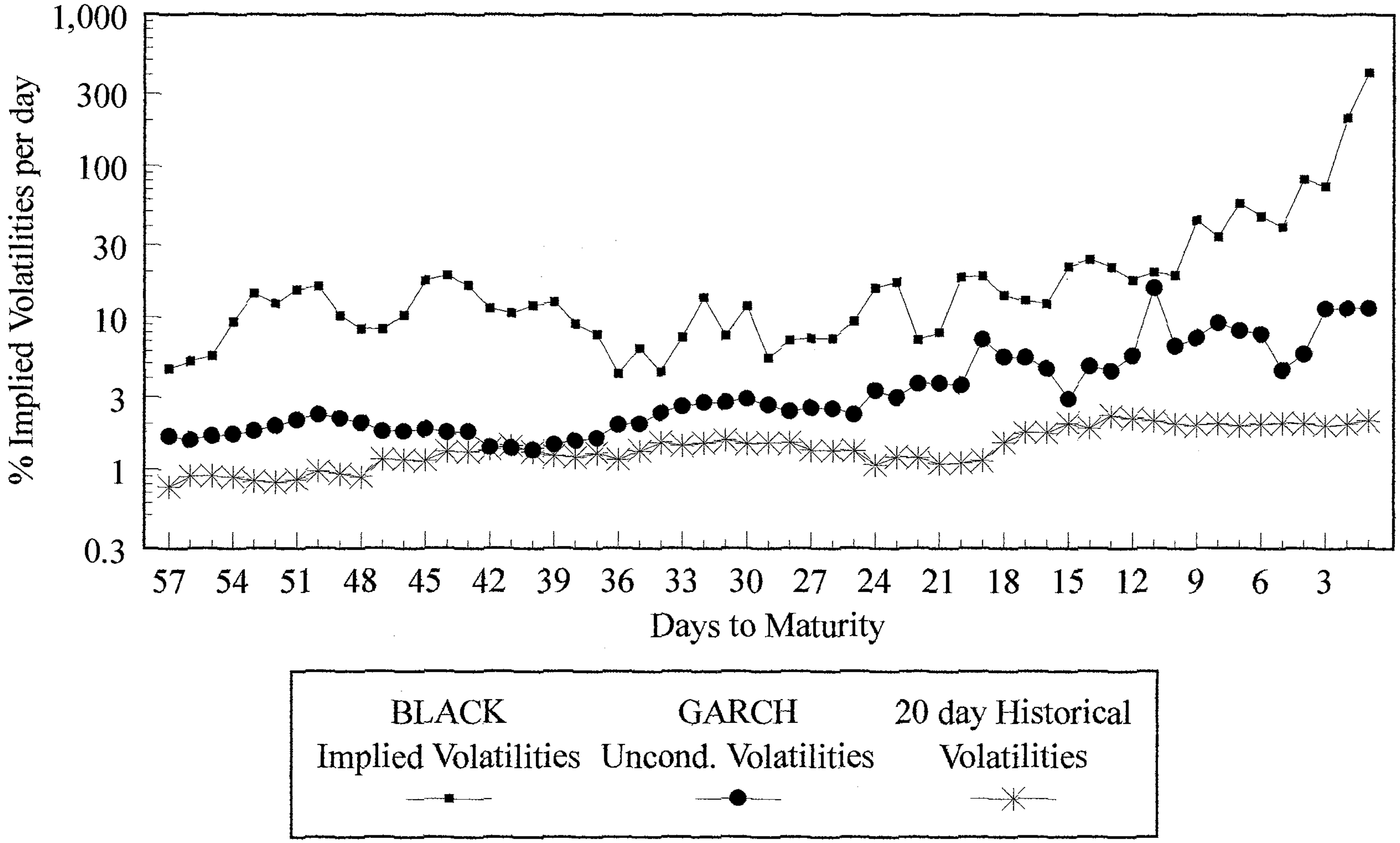


Figure 2. Chicago Wheat July Futures Contract Prices

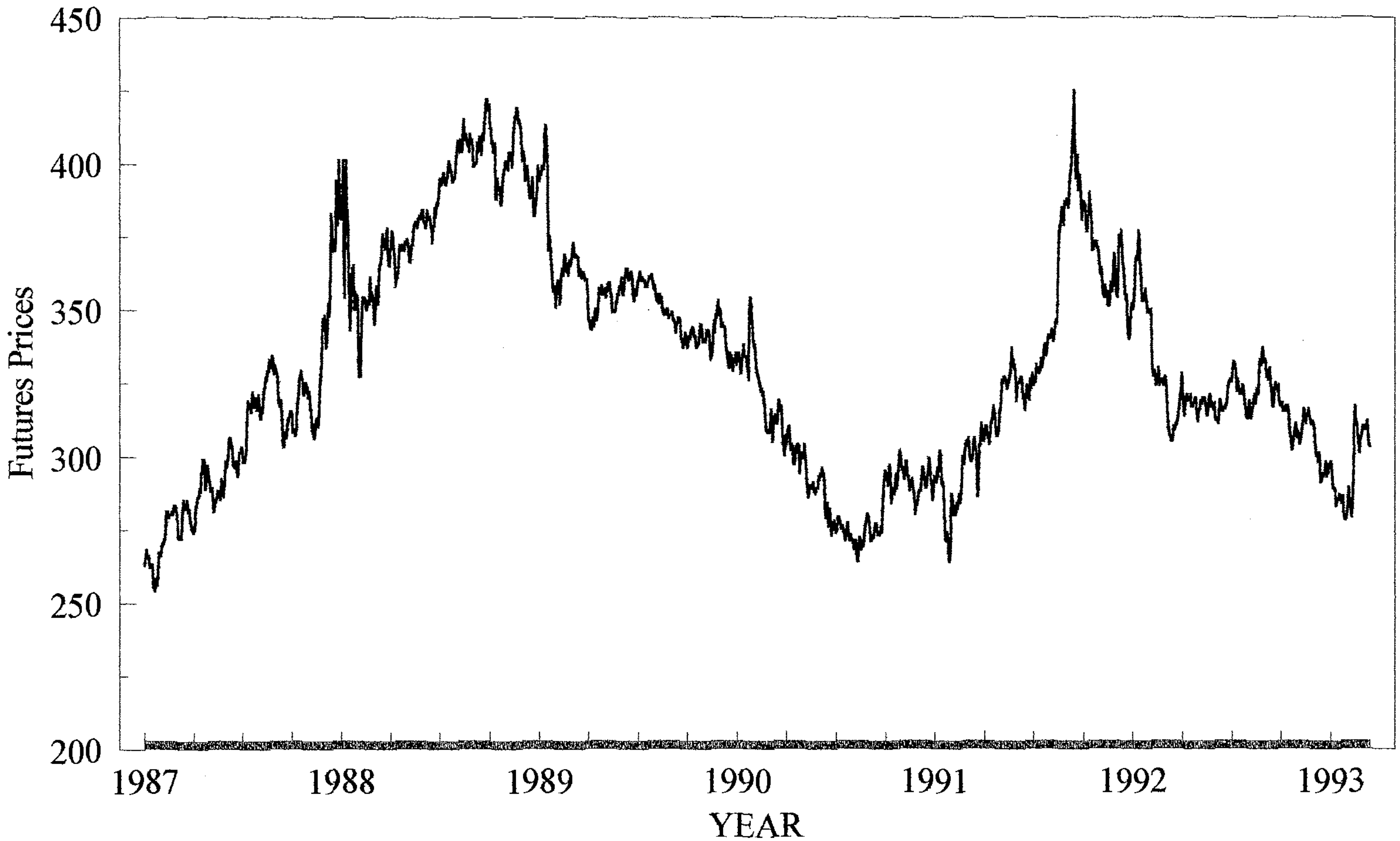
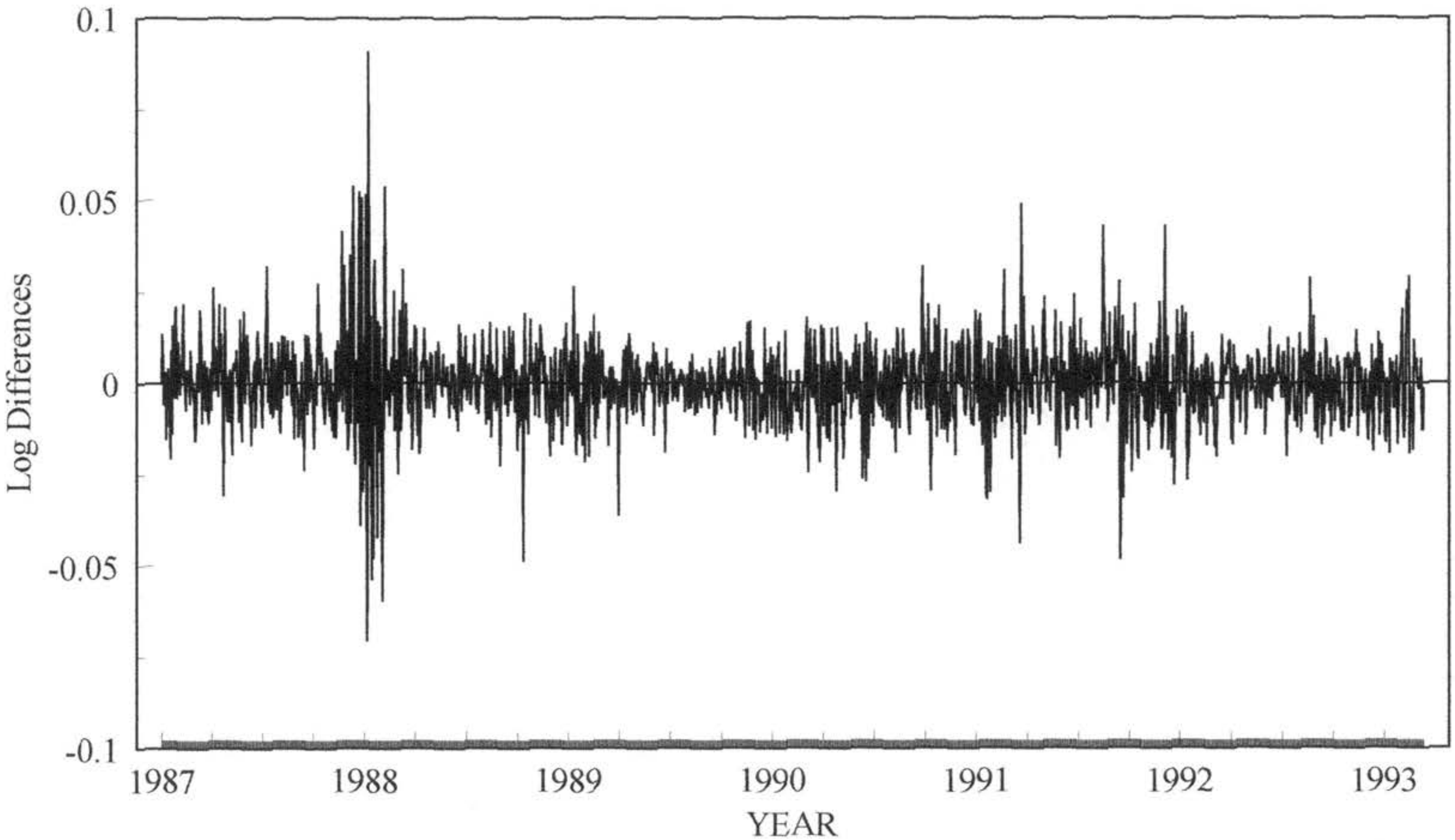


Figure 3. First Differences of the Natural Logarithms of Chicago Wheat July Futures Prices



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VITA

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