

MAKING GRAIN PRICING DECISIONS BASED
ON PROFIT MARGIN HEDGING AND REAL
OPTION VALUES

By

HYUN SEOK KIM

Bachelor of Science
Hankuk University of Foreign Studies
Seoul, Korea
2002

Master of Science
Seoul National University
Seoul, Korea
2004

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
July, 2008

MAKING GRAIN PRICING DECISIONS BASED
ON PROFIT MARGIN HEDGING AND REAL
OPTION VALUES

Dissertation Approved:

Dr. B. Wade Brorsen

Dissertation Adviser

Dr. Brian D. Adam

Dr. Kim B. Anderson

Dr. Timothy L. Krehbiel

Dr. A. Gordon Emslie

Dean of the Graduate College

ACKNOWLEDGMENT

I wish to express my sincere appreciation to my academic adviser Dr. Wade Brorsen for his intelligent supervision and invaluable guidance and encouragement throughout my Ph.D. program at Oklahoma State University. I also wish to thank all members of my academic committee, Dr. Brian Adam, Dr. Kim Anderson, and Dr. Tim Krehbiel for their helpful advice and invaluable comments during the preparation of this dissertation.

My appreciation is extended to the Department of Agricultural Economics for providing a research opportunity and financial support for my Ph.D. program. Friendly faculty and staff in the department have contributed to my academic success.

In particular, I would like to thank my parents, Ho Tak Kim and Yoon Jeung Cho, for their continuous support through prayer, hope and love which have helped me to stand firm throughout the whole process of completing this program. My wife Hae Jung and my two sons Eugene and Ian have been my continuous source of inspiration and love. Working on my Ph.D. was a lot easier with Hae Jung, Eugene and Ian on my side.

Finally, I dedicate this work to Jesus Christ, my Lord and Savior. He has begun the good work in me and has proven Himself to be faithful in finishing it. To Him be the glory forever and ever.

TABLE OF CONTENTS

Chapter	Page
I. PROFIT MARGIN HEDGING	1
Introduction	1
Theory	2
<i>Expected Target Utility</i>	2
<i>Mean Reversion</i>	6
Data	8
Procedures	10
<i>Measure of Expected Utility</i>	11
<i>Variance Ratio Test</i>	12
Results	14
Summary and Conclusions	17
References	20
Notes	23
 II. CAN REAL OPTION VALUE EXPLAIN WHY PRODUCERS APPEAR TO STORE TOO LONG?	 34
Introduction	34
Theory	35
Data	37
Procedures	38
<i>Estimation of Price Process Parameters</i>	38
<i>A Universal Lattice Model</i>	41
<i>Simulation</i>	45
Results	46
Summary and Conclusion	48
References	50

LIST OF TABLES

Table	Page
Table I–1. Average Prices (cents/bu) for Hedging Strategies at September 20 th (1975-2005).....	27
Table I–2. Paired Differences <i>t</i> -Ratios of Average Prices, (1975-2005).....	28
Table I–3. Expected Utilities for Hedging Strategies at September 20 th (1975-2005)	29
Table I–4. Paired Differences <i>t</i> -Ratios of Expected Utilities, (1975-2005).....	30
Table I–5. Average Prices and Expected Utilities for Hedging Strategies for Multiple Crops Scenario (1975-2005).....	31
Table I–6. Paired Differences <i>t</i> -Ratios of Average Prices and Expected Utilities for Multiple Crops Cases (1975-2005).....	31
Table I–7. Variance Ratio Tests for Futures Prices (1975-2006)	32
Table I–8. Joint Variance Ratio Tests for Futures Prices (1975-2006)	32
Table I–9. Variance Ratio Tests for Futures Prices Using Jackknife Approach(1975-2006)	33
Table II–1. Parameter Estimate α of Seasonal Mean Reversion Price Process	53
Table II–2. Per Period Storage Costs (Percentage of Price)	54
Table II–3. Parameter Estimates of Seasonal Mean Reversion Price Process by Nonparametric Bootstrapping.....	55
Table II–4. Sales Dates and Net Returns for Corn.....	56
Table II–5. Sales Dates and Net Returns for Soybean.....	57
Table II–6. Sales Dates and Net Returns for Wheat	58
Table II–7. Paired Differences <i>t</i> -Ratios of the Mean Net Returns between Seasonal Mean Reversion and Mean Reversion Model (1975-2006)	59

LIST OF FIGURES

Figure	Page
Figure I-1. Expected utility of a crop producer as futures price p_f^0 changes when α equals to β	24
Figure I-2. Expected utility of a crop producer as futures price p_f^0 changes when α is less than β	25
Figure I-3. Expected utility of a crop producer as futures price p_f^0 changes when α is greater than β	26
Figure II-1. An example trinomial lattice	60
Figure II-2. Seasonality of change in corn price.....	61
Figure II-3. Seasonality of change in soybean price.....	62
Figure II-4. Seasonality of change in wheat price	63
Figure II-5. Cutoff price of mean reversion price process for corn using half storage and interest costs	64
Figure II-6. Cutoff price of seasonal mean reversion price process for corn using low storage and interest costs	64
Figure II-7. Cutoff price of mean reversion price process for soybeans using low storage and interest costs.....	65
Figure II-8. Cutoff price of seasonal mean reversion price process for soybeans using low storage and interest costs	65
Figure II-9. Cutoff price of mean reversion price process for wheat using low storage and interest costs	66
Figure II-10. Cutoff price of seasonal mean reversion price process for wheat using low storage and interest costs	66

CHAPTER I

PROFIT MARGIN HEDGING

Introduction

Some extension economists and others often recommend profit margin hedging, in which a producer sells a crop preharvest by short hedging whenever prices are above a target. However, this strategy recommendation is without a research base. The strategy is also included in undergraduate textbooks such as Purcell and Koontz (pp. 329-330). With recent high prices, producers have forward contracted more of their crops, which provides evidence that some producers follow such a strategy. However, the theoretical assumptions that would justify such a strategy have never been developed.

Some empirical studies (Leuthold and Mokler 1980; Kenyon and Clay 1987; Johnson et al. 1991) have found that a profit margin hedging strategy is profitable for producers or investors but did not include significance tests. Girma and Paulson (1998) studied the statistical behavior of crack spreads (the price difference between refined energy products and crude oil) and they conclude that historically simple buy and hold trading strategies are profitable and in many instances are significantly greater than zero. These previous studies, however, do not provide any theoretical justification for using profit margin hedging.

This research focuses on answering the question, “What assumptions for producer’s utility and price process can justify profit margin hedging?” The paper determines the producer’s utility function and price processes where profit margin hedging is optimal. A statistical test of mean reversion in agricultural futures prices is conducted. Simulations are conducted to compare the expected utility of a profit margin hedging strategy with the expected utility of other strategies such as always hedging and selling at harvest.

Theory

Expected Target Utility

The goal of this section is to derive a theoretical model where profit margin hedging is optimal. The mean-variance (E-V) model is the most commonly used to analyze choices under uncertainty. Optimal hedging strategies under E-V, such as those of Johnson (1960), Stein (1960), and more general models such as Lence (1996) do not lead to profit margin hedging strategies being optimal. Similarly, mean semivariance and mean target-semivariance models such as those of Dejong et al. (1997), Lien and Tse (1998, 2000), Chen et al. (2001), and Turvey and Nayak (2003) do not lead to profit margin hedging rules being optimal. Some previous studies argue that E-V analysis has several well-known theoretical shortcomings (Fishburn 1997; Holthausen 1981). Fishburn (1977) proposed a mean-risk model which generalized the mean-target semivariance model (Markowitz 1959; Mao 1970; Hogan and Warren 1974; Porter 1974) to address the shortcomings of the E-V model. The widely known shortcoming of the E-V model is that if the outcome distributions are not of a location-scale form (such as

normal) or the utility function is not quadratic, the E-V model is not consistent with expected utility. Fishburn's model measured return as the mean of the outcomes, but defined risk as weighted deviations of outcomes below target and the model assumes risk neutrality above the target. Holthausen (1981) adapted Fishburn's model by using the same measure of risk but defining return as weighted deviations above the target to avoid the risk neutrality restriction. To measure producer's expected utility, this study adopts Holthausen's model in which the utility function is:

$$(1.1) \quad U(\pi) = \begin{cases} (\pi - t)^\beta & \text{for all } \pi \geq t \\ -k(t - \pi)^\alpha & \text{for all } \pi \leq t. \end{cases}$$

where π indicates profit, t represents the target, k is a positive constant, and α and β reflect the risk preferences. If $\alpha < 1$ ($\alpha > 1$), then the producer is risk seeking (averse) below the target. Then, the expected target utility can be written as

$$(1.2) \quad EU(\pi) = \int_t^\infty (\pi - t)^\beta f(\pi) d\pi - k \int_{-\infty}^t (t - \pi)^\alpha f(\pi) d\pi$$

where $f(\pi)$ is the probability density function of π which is normally distributed with mean $\bar{\pi}$ and variance σ_π^2 .¹ If producers hedge preharvest without basis risk, then the profit is

$$(1.3) \quad \pi = p(1 - F) + p_f^0 F$$

where p is the price of crop at harvest, F is a hedge ratio, and p_f^0 indicates the futures price at the time of the hedge. Then, equation (1.2) is rewritten as

$$(1.4) \quad EU(\pi) = \int_A^\infty \{p(1 - F) + p_f^0 F - t\}^\beta f(\pi) dp - k \int_{-\infty}^A \{t - p(1 - F) - p_f^0 F\}^\alpha f(\pi) dp$$

where

$$A = \frac{1}{1-F} (t - p_f^0 F),$$

$f(p)$ is the probability density function of p which is normally distributed with mean \bar{p} and variance σ_p^2 , and F is the choice variable. Equation (1.4) will be optimized when the first derivative with respect to F equals zero. The first order condition of equation (1.4) is

$$\begin{aligned}
(1.5) \quad EU'(\pi) = & - \int_A^\infty \beta \{p(1-F) + p_f^0 F - t\}^{\beta-1} (p - p_f^0) f(\pi) dp \\
& - \int_A^\infty \{p(1-F) + p_f^0 F - t\}^\beta \frac{\partial f(\pi)}{\partial \sigma_\pi^2} 2(1-F) \sigma_p^2 dp \\
& - \{A(1-F) + p_f^0 F - t\}^\beta f(\pi) \frac{t - p_f^0}{(1-F)^2} \\
& - k \int_{-\infty}^A \alpha \{t - p(1-F) - p_f^0 F\}^{\alpha-1} (p - p_f^0) f(\pi) dp \\
& + k \int_{-\infty}^A \{t - p(1-F) - p_f^0 F\}^\alpha \frac{\partial f(\pi)}{\partial \sigma_\pi^2} 2(1-F) \sigma_p^2 dp \\
& - k \{t - A(1-F) - p_f^0 F\}^\alpha f(\pi) \frac{t - p_f^0}{(1-F)^2}.
\end{aligned}$$

The third and the last term in equation (1.5) become zero since A equals $(t - p_f^0 F)/(1-F)$. If α and β are equal, and k is one, then equation (1.5) can be rewritten as

$$\begin{aligned}
(1.6) \quad EU'(\pi) = & - \int_A^\infty \alpha \{p(1-F) + p_f^0 F - t\}^{\alpha-1} (p - p_f^0) f(\pi) dp \\
& - \int_A^\infty \{p(1-F) + p_f^0 F - t\}^\alpha \frac{\partial f(\pi)}{\partial \sigma_\pi^2} 2(1-F) \sigma_p^2 dp
\end{aligned}$$

$$\begin{aligned}
& - \int_{-\infty}^A \alpha \{t - p(1 - F) - p_f^0 F\}^{\alpha-1} (p - p_f^0) f(\pi) dp \\
& + \int_{-\infty}^A \{t - p(1 - F) - p_f^0 F\}^{\alpha} \frac{\partial f(\pi)}{\partial \sigma_{\pi}^2} 2(1 - F) \sigma_p^2 dp .
\end{aligned}$$

Then, the first and the third terms in equation (1.6) cancel out. If price p_f^0 is above the target and all the crop is hedged – that is, F equals one – then the second and the last terms are zero and equation (1.6) will be zero. If price p_f^0 is below the target and producers do not hedge – that is, F equals zero – then there is no interior solution and the optimum is the lower bound of zero. The shape of expected utility when price p_f^0 is below the target, in figure I–1, confirms that expected utility is highest when the hedge ratio is zero. Therefore, profit margin hedging where the producer hedges all when prices are above the target and none when prices are below the target is shown to be an optimal strategy under a highly restricted target utility function where a producer has the same level of risk preferences above and below the target, and k equals one.

In the case of relaxing the assumptions that α and β are equal and k equals one, it cannot be solved analytically, so numerical methods must be used instead. Figures I–1 through I–3 show expected utilities as futures price p_f^0 changes for alternate on values of α and β . If α equals β , as in figure I–1, then a producer hedges all of the crop when the futures price is greater than the target, but does not hedge when the futures price is less than the target. In this case, profit margin hedging is optimal, confirming our theory. In the case of α smaller than β , in figure I–2, the producer’s hedging behavior is equivalent to the case of $\alpha = \beta$. In contrast to figure I–1, which is monotonic, figures I–2 and I–3 are non-monotonic. The reason why figures I–2 and I–3 are not monotonic

is that the utility function is not concave or convex; because the utility function has a different form above and below target, risk seeking dominates producers' risk preferences until some point of the hedge ratio but risk aversion dominates their risk preferences after that. Figure I-3 shows that if α is greater than β , producers hedge all of the crop when the futures price is greater than the target, but also hedges a portion of the crop when the futures price is less than the target. These numerical solutions show that profit margin hedging can be an optimal strategy when α does not equal β , but the optimal strategy is not always all or none.

Some studies (eg. Lence 1996) showed that the optimal hedge ratio typically decreases in the presence of basis risk, yield risk, transaction costs or multiple crop outputs. Moschini and Lapan (1995), for example, showed that increasing basis risk results in a lower futures hedge ratio, and increasing yield risk also results in a lower hedge ratio. Bond and Thompson (1985) found that a rise in the transaction or storage cost leads to a decrease in the optimal hedging ratio. Fackler and McNew (1993) showed that, under a multiproduct approach, the fully-hedged position is not optimal and it is not optimal to hedge all commodities in the same proportion. Relaxing these assumptions is expected to also reduce optimal hedge ratios under profit margin hedging.

Mean Reversion

Profit margin hedging has been suggested as a profit increasing strategy. Zulauf and Irwin (1998) suggest that the success of selling before harvest depends on whether a price bias exists. That is, mean reversion is a needed attribute of price behavior for profit margin hedging to be a successful strategy. Therefore, this study provides a proof that

profit margin hedging is more profitable than the other strategies such as always hedging and selling at harvest if futures prices are mean reverting.

The mean reverting futures price process can be written as

$$(1.7) \quad p - p_f^0 = \lambda(\bar{p} - p_f^0) + \varepsilon$$

where p is random cash price which equals the futures price at the terminal point of the hedge (no basis risk), p_f^0 is futures prices at the time of the hedge, \bar{p} is the long-run average price, and ε is an error term with mean zero and variance σ_ε^2 . The estimated coefficient λ is the mean reversion speed by which p_f^0 revert toward \bar{p} .

If a one-time period model is used, producers' expected profit function can be obtained by taking the expected value of equation (1.3).

$$(1.8) \quad E[\pi] = E[(1-F)p + p_f^0 F]$$

If futures price follows a mean reversion process, equation (8) can be rewritten as

$$\begin{aligned} (1.9) \quad E[\pi] &= E[(1-F)\{p_f^0 + \lambda(\bar{p} - p_f^0)\} + p_f^0 F] \\ &= E[(1-F)p_f^0 + \lambda(1-F)(\bar{p} - p_f^0) + p_f^0 F] \\ &= (1-F)p_f^0 + \lambda(1-F)(\bar{p} - p_f^0) + p_f^0 F \\ &= p_f^0 - p_f^0 F + \lambda(1-F)(\bar{p} - p_f^0) + p_f^0 F \\ &= p_f^0 + \lambda(1-F)(\bar{p} - p_f^0) \end{aligned}$$

If p_f^0 is greater than \bar{p} , then $F=1$ and we can rewrite equation (1.9) as

$$(1.10) \quad E[\pi|PMH, p_f^0 > \bar{p}] = p_f^0 = E[\pi|AH] > p_f^0 + \lambda(\bar{p} - p_f^0) = E[p] = E[\pi|SH]$$

where PMH indicates profit margin hedging, AH indicates always hedging, and SH is Selling at harvest.

If p_f^0 is less than \bar{p} , then $F = 0$ and we can rewrite equation (1.9) as

$$(1.11) \quad E[\pi|PMH, p_f^0 < \bar{p}] = p_f^0 + \lambda(\bar{p} - p_f^0) = E[\pi|SH] > p_f^0 = E[\pi|AH].$$

Since λ is greater than zero and the futures price p_f^0 is less than the long-run average price \bar{p} , the expected profit conditioned on profit margin hedge is greater than p_f^0 which is the expected profit conditioned on always hedging. Therefore, profit margin hedging is more profitable than other strategies such as always hedging and selling at harvest, if futures prices are mean reverting.

It is important to note that the above derivation is based on a static one-period model. If the problem is made dynamic and producers are allowed to hedge at anytime, the profit margin hedging rule would still be profitable, but would no longer be optimal. The optimal rule could be derived similarly to what Fackler and Livingston (2002) derived for cash prices. In their model, if grain prices are below the mean, it is best to store since prices will revert to the mean. If grain prices are unusually high, it is best to sell immediately. If prices are near the mean, there can be a real option value from waiting since there is the opportunity to wait and select a time to sell when prices are unusually high. In that case, the expected profit maximizing target price would decrease as harvest approaches since there is less opportunity for price to increase above the mean.

Data

The chosen agricultural commodities are Oklahoma hard red winter wheat, Illinois soft winter wheat, soybeans, and corn. This study uses the July futures contract prices for wheat from the Kansas City Board of Trade (KCBT) and from the Chicago

Board of Trade (CBOT), November futures contract prices for soybeans and December futures contract prices for corn from the CBOT. Futures prices for KCBT wheat are obtained from KCBT and for CBOT wheat, soybean, and corn are obtained from Prophet Financial Systems, Inc.

To test mean reversion, this study uses daily data. The sample period extends from August 1975 through May 2006 for KCBT and CBOT wheat, from December 1975 through October 2006 for soybeans and January 1975 through December 2006 for corn. July observations for KCBT and CBOT wheat, November observations for CBOT soybeans and corn are deleted since these observations are for the delivery period. Markets are thin during this time and can be quite volatile. No price changes across contract years are used.

To conduct the simulation, Oklahoma June average wheat cash prices and prices for the July futures contract on September 20th from 1975 to 2005 are used. We use 31 years data for simulations whereas 32 years data for a mean reversion test since we do not have the 2006 economic cost of production. Five year moving averages of basis and yield of crops are used to make hedging decisions with basis risk and yield risk. For the case of multi-crop producers, the study used Illinois June average cash price for wheat, and Illinois October average price for soybean and corn.

For Illinois wheat, the July futures contract prices on September 20th from 1975 through 2005 are used. For Illinois soybean and corn, futures prices for the November contract and the December contract for soybean and corn, respectively, at May 10th from 1975 through 2005 are used. The Illinois monthly average cash prices are obtained from National Agricultural Statistics Service (NASS) of the United States Department of

Agriculture (USDA). This study used 70% of economic costs of production as targets for KBCT wheat and 80% for CBOT wheat and 100% for CBOT corn and soybean since the economic costs include many types of cost and it is too high to use as the target in KBCT and CBOT wheat. These choices depend on the number of hedges for the 32 year period. If the cost is set too high, a producer would seldom hedge. If cost is set too low, a producer would always hedge. For the costs assumed here, a hedge is placed 16 times of 31 years for KBCT wheat, 17 times for CBOT wheat, 16 times for CBOT corn, 20 times for CBOT soybean. The economic costs of production for the three crops from 1975 to 2005 are obtained from the Economic Research Service (ERS) of USDA (2008). The yield data of Oklahoma wheat at Garfield County, Oklahoma, and Illinois wheat, soybean, and corn in Livingston County, Illinois from 1975 to 2005 are obtained from NASS of USDA.

Procedures

This paper has two main procedures – simulation to compare the expected utility of profit margin hedging strategy with the always hedging and the selling at harvest strategies, and mean reversion testing for KCBT and CBOT wheat July futures prices, CBOT soybean November futures prices, and CBOT corn December futures prices. The expected utility is measured by taking the average utility across 31 years. To test mean reversion, the variance ratio test is employed.

Measure of Expected Utility

Five scenarios are considered for each of three hedging strategies – hedging without risk, with basis risk, with yield risk, with yield and basis risk and with multiple crops. To measure expected utility without basis risk, a perfect foresight model is used which assumes actual harvest basis is known at the time of the decision. In this case, under a profit margin hedging strategy, if the sum of futures price at the time of the decision and foresighted basis is greater than the target return, then producers hedge all crops, otherwise they hedge none and sell the crops at harvest.

If basis risk were considered, producers hedge all when the sum of futures price at the time of the decision and average basis is greater than the target return otherwise they do not hedge. With yield risk, producers hedge all crops if the average returns that is the sum of futures price at the time of the decision and the foresighted basis multiplied by average yield is greater than the target multiplied by average yield. In the case of multiple crops, the producer hedges all crops when the total returns – that is, the sum of futures price at the time of the decision and foresighted basis multiplied by quantity produced for each crop – is greater than the total target that is the sum of target multiplied by quantity produced for each crop.

We assume producers are risk averse above the target and risk seeking below the target and pick 0.5 as the value of α and β . We also assume a transaction cost of 1.2 cents per bushel but we do not consider margin calls. After calculating utility for 31 years from 1975 through 2005, expected utility is calculated as the average of utilities

$$(14) \quad EU(\pi) = \frac{1}{31} \sum_{i=1}^{31} U(\pi_i) .$$

Variance Ratio Test

The idea behind the variance ratio test is that if the natural logarithm of a price series P_t is a random walk, then the variance of k -period returns should equal k times the variance of one-period returns (Cochrane 1988; Kim et al. 1991; Lo and MacKinlay 1988; Poterba and Summers 1988). The general k -period variance ratio, $VR(k)$ is defined as

$$(15) \quad VR(k) = \frac{\sigma^2(k)}{k\sigma^2(1)}$$

where $\sigma^2(k)$ is the variance of the k differences and $\sigma^2(1)$ is the variance of the first differences. The null hypothesis of interest is that $VR(k)$ equals one. That is, $VR(k)$ equal to one implies that futures price follows a random walk process, whereas a variance ratio of less than one implies a mean reversion process.

Lo and MacKinlay (1988) show that the variance ratio estimator can be calculated as

$$(16) \quad \sigma^2(k) = \frac{1}{m} \sum_{t=k}^{nk} (P_t - P_{t-k} - k\hat{\mu})^2,$$

where

$$m = k(nk - k + 1) \left(1 - \frac{k}{nk}\right) \text{ and}$$

$$(17) \quad \sigma^2(1) = \frac{1}{(nk-1)} \sum_{t=1}^{nk} (P_t - P_{t-1} - \hat{\mu})^2,$$

in which

$$\hat{\mu} = \frac{1}{nk} \sum_{t=1}^{nk} (P_t - P_{t-1}) = \frac{1}{nk} (P_{nk} - P_0),$$

where P_0 and P_{nk} are the first and last observations of the price series. Since futures returns have been shown to exhibit conditional heteroscedasticity (Yang and Brorsen 1993), we computed the asymptotic variance of the variance ratio, $\phi(k)$, under heteroscedasticity. The standard normal test statistic (Lo and MacKinlay 1988) is

$$(18) \quad Z(k) = \frac{VR(k) - 1}{[\phi(k)]^{1/2}} \xrightarrow{a} N(0, 1)$$

where

$$\phi(k) = \sum_{j=1}^k \left[\frac{2(k-1)}{k} \right]^2 \hat{\delta}(j)$$

and

$$\hat{\delta}(j) = \frac{\sum_{t=j+1}^{nk} (p_t - p_{t-1} - \hat{\mu})^2 (p_{t-j} - p_{t-j-1} - \hat{\mu})^2}{\left[\sum_{t=1}^{nk} (p_t - p_{t-1} - \hat{\mu})^2 \right]^2}.$$

Chow and Denning (1993) derived the joint period test where the null hypothesis is $VR(k_i)$ equals one for $i = 1, \dots, l$. The test statistic can be written as

$$(19) \quad ZV = \max_{1 \leq i \leq l} |Z(k_i)|$$

which asymptotically follows the studentized maximum modulus distribution (Stoline and Ury 1979) under the martingale null hypothesis.

This study also conducts a variance ratio test using a new jackknife method because of possible nonnormality. Specially, we use a jackknife approach where each year is treated as a unit, so we delete each year of observations from the data set for each sample. Then, the jackknife estimate of k -period variance ratio of futures price $\tilde{\theta}(k)$ is defined in the usual manner. Let $\theta(k)$ be the k -period variance ratio of futures prices and

$\tilde{\theta}_i(k)$ be the k -period variance ratio when the i th year observations are deleted from the data set. Since we use 32 years data set from 1975 through 2006 for a mean reversion test, the jackknife estimate of k -period variance ratio is calculated as the average of $\tilde{\theta}_i(k)$

$$(21) \quad \tilde{\theta}(k) = \frac{1}{32} \sum_{i=1}^{32} \tilde{\theta}_i(k).$$

The jackknife estimate of the standard error of $\tilde{\theta}(k)$ is

$$(22) \quad \tilde{\sigma}_{\tilde{\theta}}(k) = \left[\frac{31}{32} \sum_{i=1}^{32} \{ \tilde{\theta}_i(k) - \tilde{\theta}(k) \}^2 \right]^{1/2}.$$

Then, the test statistic should be

$$(23) \quad t(k) = \frac{\tilde{\theta}(k) - 1}{\tilde{\sigma}_{\tilde{\theta}}(k)} \sim t_{(df=31)}.$$

This jackknife approach is similar to that used with the Agricultural Resource Management Survey (ARMS) and described by Dubman (2000).

Results

Table I–1 shows that achieves the highest average prices in all scenarios for all crops, followed by always hedging and selling at harvest. Table I–2 presents the results of the paired difference tests of average prices for the profit margin hedging and other strategies. The average prices of paired profit margin hedging and always hedging are not significantly different from zero at a 5% significance level in all scenarios for all crops except in no risk and yield risk scenarios for CBOT soybeans. The average prices of profit margin hedging and selling at harvest strategies are significantly different from

zero at the 5% significance level in all scenarios for all crops except in basis risk scenario for KCBT wheat.

Table I–3 shows the expected utilities for the hedging strategies. The expected utilities of profit margin hedging are higher than the other strategies which confirm the theoretical findings. Always hedging has a higher expected utility than selling at harvest in all scenarios. The results of the paired difference tests of expected utilities for the profit margin hedging and other strategies are presented in table I–4. The expected utilities of paired profit margin hedging and always hedging are not significantly different from zero at a 5% significance level in all scenarios for all crops except the cases of no risk and yield risk for CBOT soybean. The expected utilities of profit margin hedging and selling at harvest are significantly different from zero at the 5% significance level except in basis risk, and yield and basis risk scenarios for KCBT wheat and basis risk scenarios for CBOT soybean. Thus, the expected utility results reflect that preharvest prices were higher than harvest prices during this time period.

Table I–5 shows average prices and the expected utilities in the multiple crops scenario. In the case of multiple crops, the average prices of the independent profit margin hedging are the highest, followed by profit margin hedging, always hedging and selling at harvest, respectively. The expected utility of the independent profit margin hedging strategy is the highest followed by profit margin hedging, always hedging, and selling at harvest strategy, respectively.

Table I–6 presents the results of the paired difference tests of average prices and expected utilities for multiple crops case. We do not find any evidence that the average prices and expected utilities of profit margin hedging and always hedging strategies are

significantly different from zero at a 5% significance level. However, the average prices and expected utilities of profit margin hedging and selling at harvest are significantly different from zero at the 5% significance level. The table also shows that the average prices and expected utilities of profit margin hedging and independent profit margin hedging is significantly different from zero at a 5% significance level.

These results show that adding both price risk and yield risk reduces the expected utility of the profit margin hedging rule. Also, if producers grow multiple crops, the profit margin hedging rule would not be optimal even with a target utility function. Thaler's (1980) mental accounting where producers consider their price risk and yield risk separately or divide their profits for each crop into separate pockets of money is proposed as a possible explanation of the popularity of profit margin hedging.

The result of the variance ratio tests in tables I-7 and I-8 show that both Z -statistic and ZV -statistic values are not significantly different from 1.0 at the 5% significance level for all crops which means there is little evidence of mean reversion in futures prices for all crops. Table I-9 shows the result of the variance ratio test using the jackknife approach. None of the t -statistics show significant differences from one at the 5% significance level for all crops which confirms the results that there is little evidence of mean reversion in futures prices for all crops. Many of the estimated variance ratios are even greater than one (although insignificant) which would indicate trend following rather than mean reversion. If prices were trend following then using a technical analysis rule would be optimal.

As shown in the theory section, profit margin hedging can be profitable if futures prices are mean reverting. However, our mean reversion test results show no evidence of

mean reversion in future prices. Furthermore, simulation results show that although profit margin hedging is more profitable than selling at harvest in most cases, there is little evidence that profit margin hedging is more profitable than always hedging except in a few cases. Two possible explanations have been offered for the profitability of preharvest hedging over this time period. One is that more buyers than sellers are wanting to lock in prices and so the buyers are paying a risk premium. If this hypothesis were correct, then the recent introduction of index funds (Sanders et al. 2008) would serve to make preharvest hedging even more attractive. The other hypothesis is that the market priced a small probability catastrophic event, which never happened during this time period. If this hypothesis were correct, adding the 2008 crop year might remove the apparent profitability of preharvest hedging.

Summary and Conclusions

Some extension economists and others often recommend profit margin hedging in choosing the timing of crop sales. This paper determines producer's utility function and price processes where profit margin hedging is optimal. Profit margin hedging is an optimal strategy under a highly restricted target utility function even in an efficient market. Profit margin hedging can be profitable if prices are mean reverting.

Simulations are conducted to compare the expected utility of profit margin hedging strategies with the expected utility of other strategies such as always hedging and selling at harvest. A variance ratio test is conducted to test for the existence of mean reversion in agricultural futures prices. The simulation results show that the expected utility of profit margin hedging is higher than always hedging and selling at harvest

strategies except in a few scenarios such as yield and basis risk for CBOT wheat and yield risk and yield and basis risk for CBOT corn. Therefore, this result suggests that the profit margin hedging would give the highest expected utility to producers in most cases under the specified utility function. However, if a producer grows multiple crops or considers both price risk and yield risk, the expected utility of profit margin hedging strategy could be reduced and not be optimal even with a target utility function. Mental accounting where producers consider their price risk and yield risk separately or divide their profits for each crop into separate pockets of money is proposed as a possible explanation of the popularity of profit margin hedging.

The paired differences tests of average prices and expected utilities for the profit margin hedging and the other two strategies shows that, in most cases, both average prices and expected utilities of profit margin hedging strategies are not significantly different from those of always hedging strategies, but are higher than those of selling at harvest strategies except in some yield and basis risk scenarios. This may be the result of the time period being a time of unusually stable prices or it could be due to buyers being more eager to lock in prices than seller.

With the variance ratio test, there is little evidence that futures prices of all crops follow a mean reverting process. The results of variance ratio test using jackknife approach confirm the result that there is insufficient evidence to conclude that futures prices of all crops follow a mean reverting process.

Since we do not find evidence of mean reversion in futures prices and profit margin hedging is not more profitable than always hedging except in a few cases, we rely primarily on the theoretical proof using the shape of utility functions in figures I-1

through I-3 as the primary justification to argue that profit margin hedging can be the preferred strategy.

References

- Bond, G.E., and S.R. Thompson. 1985. "Risk Aversion and the Recommended Hedging Ratio." *American Journal of Agricultural Economics* 67:870–72.
- Chen, S., C. Lee, and K. Shrestah. 2001. "On a Mean-Generalized Semivariance Approach to Determining the Hedge Ratio." *Journal of Futures Markets* 21:581–98.
- Chow, K.V., and K. Denning. 1993. "A Simple Multiple Variance Ratio Test." *Journal of Econometrics* 58:385–401.
- Cochrane, J.H. 1988. "How Big Is the Random Walk in GNP?" *Journal of Political Economy* 96:893–920.
- Dejong, A., F. de Roons, and C. Veld. 1997. "Out-of-Sampling Hedging Effectiveness of Currency Futures for Alternative Models and Hedging Strategies." *Journal of Futures Markets* 17:817–37.
- Dubman, R. 2000. "Variance Estimation with USDA's Farm Costs and Returns Surveys and Agricultural Resource Management Survey." Staff Report, AGES 00-01, Economic Research Service, U.S. Department of Agriculture.
- Fackler, P.L., and K.P. McNew. 1993. "Multiproduct Hedging: Theory, Estimation, and an Application." *Review of Agricultural Economics* 15:521–35.
- Fackler, P.L., and M.J. Livingston. 2002. "Optimal Storage by Crop Producers." *American Journal of Agricultural Economics* 84:645–59.
- Fishburn, P.C. 1977. "Mean-Risk Analysis Associated with Below-Target Returns." *American Economic Review* 67:116–126.
- Hogan, W.W., and J.M. Warren. 1974. "Toward the Development of an Equilibrium Capital Market Model." *Journal of Financial and Quantitative Analysis* 9:1–11.
- Holthausen, D.M. 1981. "A Risk-Return Model with Risk and Return Measured as Deviations from a Target Return." *American Economic Review* 71:182–188.

- Irwin, S.H., C.R. Zulauf, and T.E. Jackson. 1996 "Monte Carlo Analysis of Mean Reversion in Commodity Futures Prices." *American Journal of Agricultural Economics* 78:387–399.
- Johnson, L.L. 1960. "The Theory of Hedging and Speculation in Commodity Futures." *The Review of Economic Studies* 27:139–51
- Johnson, R.L., C.R. Zulauf, S.H. Irwin, and M.E. Gerlow. 1991. "The Soybean Complex Spread: An Examination of Market Efficiency from the Viewpoint of a Production Process." *The Journal of Futures Markets* 11:25–37.
- Kansas City Board of Trade (KCBT). Available at http://www.kcvt.com/historical_data.asp
- Kenyon, D., and J. Clay. 1987. "Analysis of Profit Margin Hedging Strategies for Hog Producers." *The Journal of Futures Markets* 7:183–202.
- Kim, M.J., C.R. Nelson, and R. Startz. 1991. "Mean Reversion in Stock Prices? A Reappraisal of the Empirical Evidence." *Review of Economic Studies* 58:515–28.
- Lence, S.H. 1996. "Relaxing the Assumptions of Minimum-Variance Hedging." *Journal of Agricultural and Resource Economics* 21:39–55.
- Leuthold, R.L., and R.S. Mokler. 1980. "Feeding-Margin Hedging in the Cattle Industry." *Futures Trading Seminar Proceedings, Board of Trade of the City of Chicago*, 6:56–68.
- Lien, D., and Y.K. Tse. 2000. "Hedging Time-Varying Downside Risk." *Journal of Futures Markets* 18:705–22.
- Lo, A.W., and A.C. MacKinlay. 1988. "Stock Market Prices Do Not Follow Random Walks: Evidence from Simple Specification Test." *Review of Financial Studies* 1:41–66.
- Mao, J.C.T. 1970. "Models of Capital Budgeting, E-V vs E-S." *Journal of Financial and Quantitative Analysis* 4:657–675.
- Markowitz, H.M. 1959. *Portfolio Selection: Efficient Diversification of Investments*. New Haven: Yale University Press.
- Moschini, G., and H. Lapan. 1995. "The Hedging Role of Options and Futures Under Joint Price, Basis, and Production Risk." *International Economic Review* 36:1025–49.
- Porter, R.B. 1974. "Semivariance and Stochastic Dominance: A Comparison." *American Economic Review* 64:200–04.

- Poterba, J.M., and L.H. Summers. 1988. "Mean Reversion in Stock Prices: Evidence and Implications." *Journal of Financial Economics* 22:27–59.
- Prophet Financial Systems, Inc. 2006. Unpublished electronic database. Palo Alto, CA.
- Purcell, W.D., and S.R. Koontz. 1999. *Agricultural Futures and Options: Principles and Strategies*. Upper Saddle River, NJ: Prentice Hall.
- Sanders, D.R., S.H. Irwin, and R.P. Merrin. 2008. "The Adequacy of Speculation in Agricultural Futures Markets: Too Much of a Good Thing?" Marketing and Outlook Research Report 2008-02. Department of Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign.
- Stein, J.L. 1961. "Simultaneous Determination of Spot and Futures Prices" *American Economic Review* 51:1012–25
- Stoline, M.R., and H.K. Ury. 1979. "Tables of the Studentized Maximum Modulus Distribution and an Application to Multiple Comparisons Among Means." *Technometrics* 21:87–93
- Thaler, R. 1980. "Toward a Positive Theory of Consumer Choice." *Journal of Economic Behavior and Organization* 1:39–60.
- Turvey, C.G., and G. Nayak. 2003. "The Semivariance-Minimizing Hedge Ratio." *Journal of Agricultural and Resource Economics* 28:100–15.
- U.S. Department of Agriculture (USDA), Economic Research Service (ERS). 2008. Available at <http://www.ers.usda.gov/Data/CostsAndReturns/testpick.htm>. Accessed on 12 February 2008.
- U.S. Department of Agriculture (USDA), National Agricultural Statistic Service (NASS). 2008. Available at <http://www.nass.usda.gov/QuickStats/>. Accessed on 12 February 2008
- Yang, S.-R., and B.W. Brorsen. 1993. "Nonlinear Dynamics of Daily Futures Prices: Conditional Heteroskedasticity or Chaos?" *The Journal of Futures Markets* 13:175–91.
- Yoon, B.-S., and B.W. Brorsen. 2005. "Can Multiyear Rollover Hedging Increase Mean Returns?" *Journal of Agricultural and Applied Economics* 37:65–78.
- Zulauf, C.R., and S.H. Irwin. 1998. "Market Efficiency and Marketing to Enhance Income of Crop Producers." *Review of Agricultural Economics* 20:308–31.

Notes

1. The variance of profit, σ_π^2 , equals $(1 - F)^2 \sigma_p^2$ where σ_p^2 is variance of p .

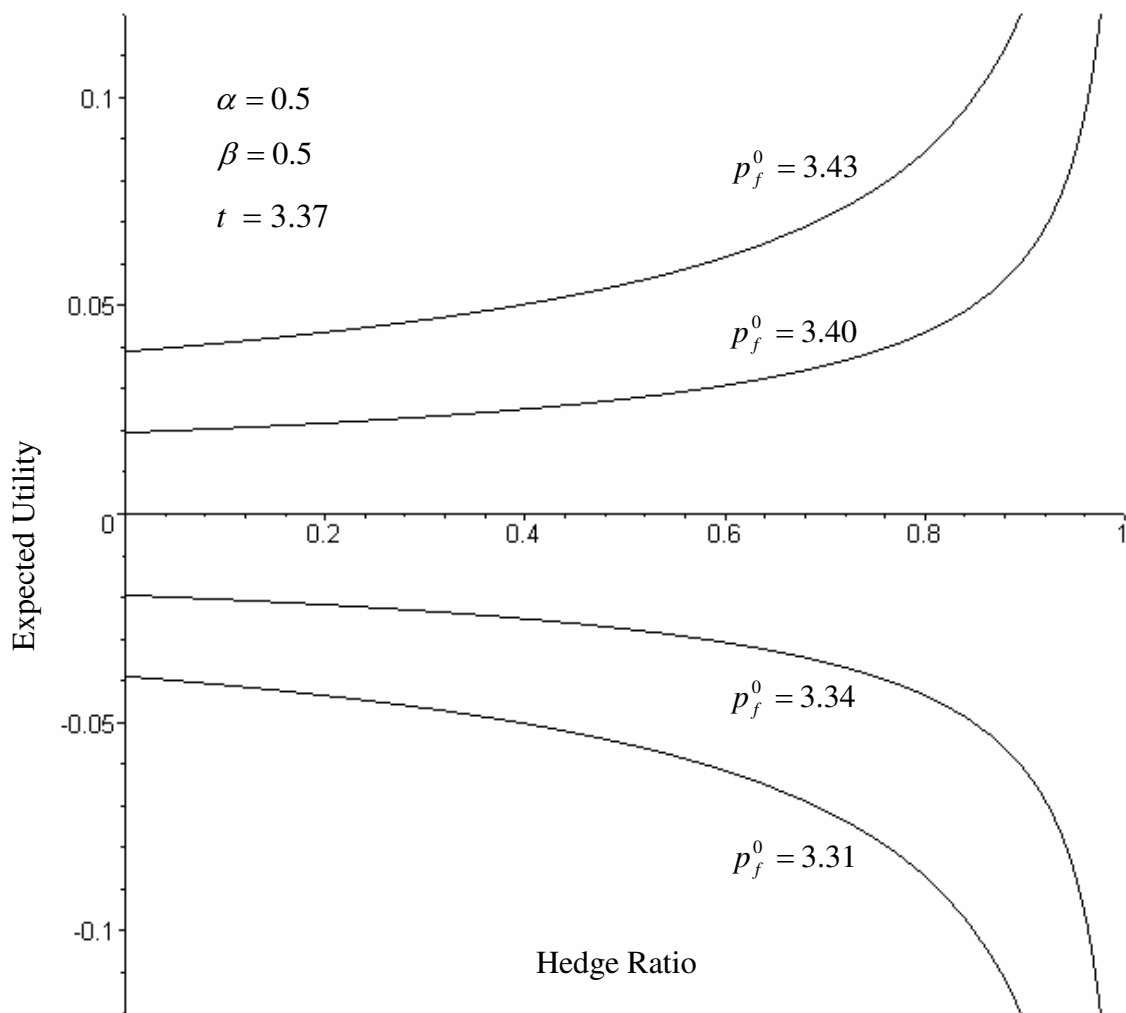


Figure I–1. Expected utility of a crop producer as futures price p_f^0 changes when α equals to β

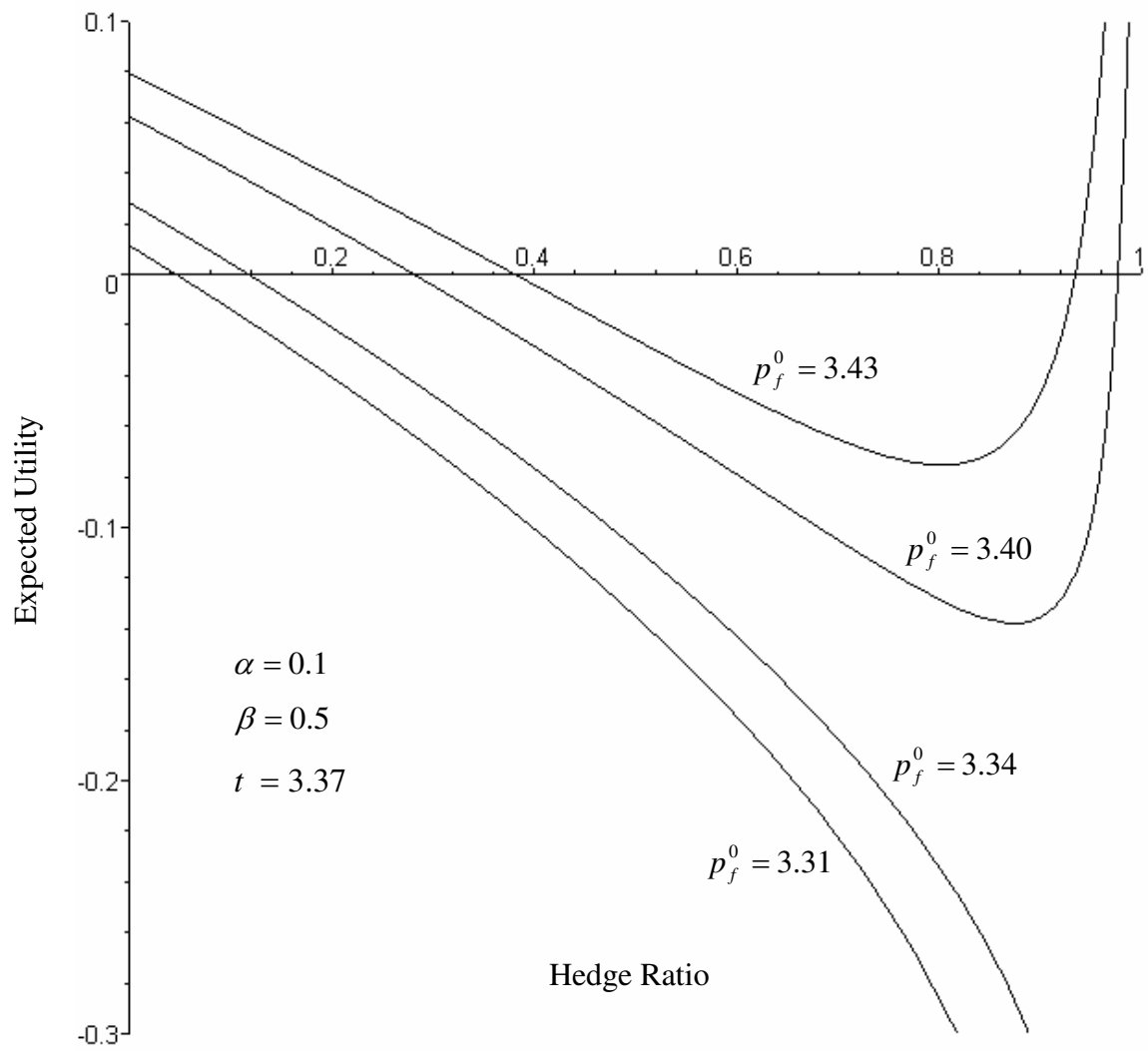


Figure I-2. Expected utility of a crop producer as futures price p_f^0 changes when α is less than β

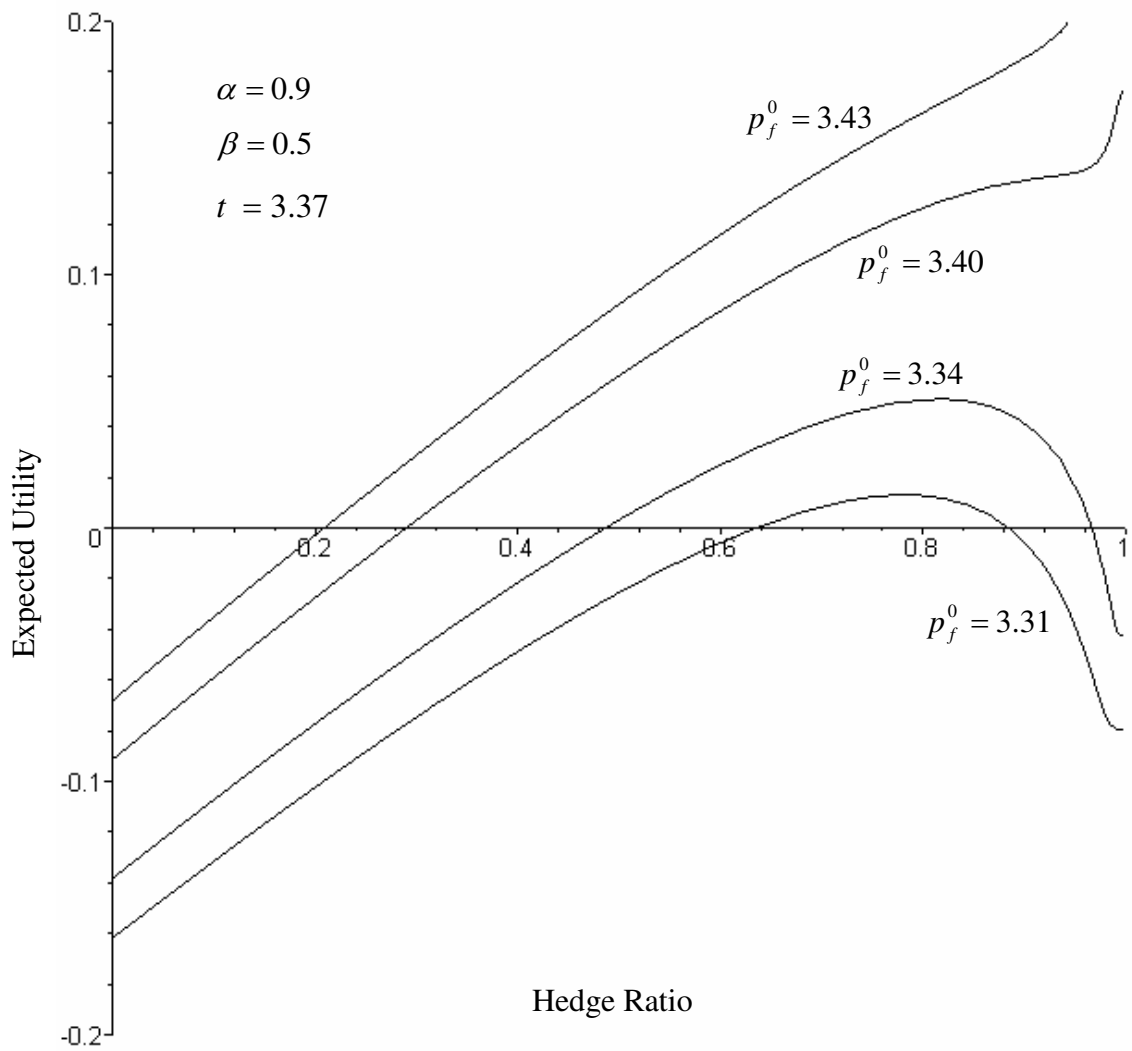


Figure I-3. Expected utility of a crop producer as futures price p_f^0 changes when α is greater than β

Table I–1. Average Prices (cents/bu) for Hedging Strategies at September 20th (1975-2005)

Commodity	Scenario	Strategies		
		Profit Margin Hedging	Always Hedging	Selling at Harvest
KCBT Wheat	No risk	330.10	319.78	311.03
	Basis risk	327.13	319.78	311.03
	Yield risk	329.11	318.24	311.03
	Yield and basis risk	328.09	318.24	311.03
CBOT Wheat	No risk	320.73	312.58	297.29
	Basis risk	319.93	312.58	297.29
	Yield risk	319.81	308.83	297.29
	Yield and basis risk	318.99	308.83	297.29
CBOT Corn	No risk	241.26	238.94	224.81
	Basis risk	239.97	238.94	224.81
	Yield risk	238.65	230.26	224.81
	Yield and basis risk	237.32	230.26	224.81
CBOT Soybean	No risk	631.02	605.66	581.52
	Basis risk	618.94	605.66	581.52
	Yield risk	626.50	597.92	581.52
	Yield and basis risk	613.21	597.92	581.52

Table I–2. Paired Differences *t*-Ratios of Average Prices, (1975-2005)

Commodity	Scenario	Paired Differences	
		Profit Margin Hedging vs. Always Hedging	Profit Margin Hedging vs. Selling at Harvest
KCBT Wheat	No risk	1.47	2.39*
	Basis risk	1.13	1.78
	Yield risk	1.30	2.55*
	Yield and basis risk	1.26	2.19*
CBOT Wheat	No risk	1.23	2.88*
	Basis risk	1.10	2.79*
	Yield risk	1.37	2.88*
	Yield and basis risk	1.25	2.78*
CBOT Corn	No risk	0.47	3.16*
	Basis risk	0.13	2.86*
	Yield risk	1.10	3.19*
	Yield and basis risk	0.82	3.26*
CBOT Soybean	No risk	2.22*	4.22*
	Basis risk	1.43	2.45*
	Yield risk	2.26*	4.29*
	Yield and basis risk	1.47	2.16*

Note: *t*-critical value with 30 degrees of freedom at 5% significance level is 2.042.

* indicates significance at 5% level.

Table I-3. Expected Utilities for Hedging Strategies at September 20th (1975-2005)

Commodity	Scenario	Strategies		
		Profit Margin Hedging	Always Hedging	Selling at Harvest
KCBT Wheat	No risk	2.15	0.93	0.57
	Basis risk	1.79	0.93	0.57
	Yield risk	1.82	0.85	0.57
	Yield and basis risk	1.74	0.85	0.57
CBOT Wheat	No risk	1.94	0.73	-0.81
	Basis risk	1.75	0.73	-0.81
	Yield risk	1.87	0.55	-0.81
	Yield and basis risk	1.67	0.55	-0.81
CBOT Corn	No risk	0.48	-0.25	-2.28
	Basis risk	0.03	-0.25	-2.28
	Yield risk	0.20	-0.86	-2.28
	Yield and basis risk	-0.22	-0.86	-2.28
CBOT Soybean	No risk	6.44	3.81	2.55
	Basis risk	5.03	3.81	2.55
	Yield risk	6.25	3.44	2.55
	Yield and basis risk	4.75	3.44	2.55

Note: We use $\alpha = \beta = 0.5$ as levels of risk preference below and above target.

Table I–4. Paired Differences *t*-Ratios of Expected Utilities, (1975-2005)

Commodity	Scenario	Paired Differences	
		Profit Margin Hedging vs. Always Hedging	Profit Margin Hedging vs. Selling at Harvest
KCBT Wheat	No risk	1.64	2.51*
	Basis risk	1.46	1.49
	Yield risk	1.28	2.47*
	Yield and basis risk	1.40	1.81
CBOT Wheat	No risk	1.71	3.07*
	Basis risk	1.36	2.92*
	Yield risk	1.78	3.13*
	Yield and basis risk	1.41	2.94*
CBOT Corn	No risk	1.19	3.64*
	Basis risk	0.39	3.17*
	Yield risk	1.51	3.75*
	Yield and basis risk	0.91	2.89*
CBOT Soybean	No risk	2.42*	4.43*
	Basis risk	1.52	1.84
	Yield risk	2.44*	4.38*
	Yield and basis risk	1.54	1.63

Note: *t*-critical value with 30 degrees of freedom at 5% significance level is 2.042.

* indicates significance at 5% level.

Table I–5. Average Prices and Expected Utilities for Hedging Strategies for Multiple Crops Scenario (1975-2005)

Item	Strategies			
	Profit Margin Hedging	Independent Profit Margin Hedging	Always Hedging	Selling at Harvest
Average Prices (\$/bu)	75.46	76.46	75.39	70.53
Expected Utilities	29.57	63.99	20.99	-10.58

Note: The dates of decision making are September 20th for CBOT wheat and May 10th for CBOT soybean and corn.

We use $\alpha = \beta = 0.5$ as levels of risk preference below and above target.

Table I–6. Paired Differences *t*-Ratios of Average Prices and Expected Utilities for Multiple Crops Cases (1975-2005)

Item	Paired Difference		
	Profit Margin Hedging vs. Always Hedging	Profit Margin Hedging vs. Selling at Harvest	Profit Margin Hedging vs. Independent Profit Margin Hedging
Average Prices	0.07	3.47*	-2.42*
Expected Utilities	0.98	3.66*	-2.99*

Note: *t*-critical value with 30 degrees of freedom at 5% significance level is 2.042.

* indicates significance at 5% level.

Table I–7. Variance Ratio Tests for Futures Prices (1975-2006)

Commodity	Return Horizon (k-days)	Variance Ratio	Z-statistic
KBCT Wheat	2	1.020	0.892
	5	0.984	-0.232
	10	0.977	-0.200
	20	0.938	-0.377
CBOT Wheat	2	1.007	0.357
	5	0.952	-0.738
	10	0.922	-0.842
	20	0.848	-1.056
CBOT Corn	2	1.033	1.857
	5	1.046	0.547
	10	1.048	0.510
	20	1.094	0.643
CBOT Soybean	2	1.001	0.068
	5	0.995	-0.091
	10	0.963	-0.398
	20	0.991	-0.068

Note: July observations are deleted.

Standard normal distribution Z at 5% significance level is 1.96.

Table I–8. Joint Variance Ratio Tests for Futures Prices (1975-2006)

Commodity	VR(2)	ZV
KCBT Wheat	1.020	0.892
CBOT Wheat	1.006	1.056
CBOT Corn	1.033	1.857
CBOT Soybean	1.001	0.431

Note: July observations are deleted.

Studentized maximum modulus distribution with 20 and infinity degree of freedom at 5% significance level is 3.643.

Table I–9. Variance Ratio Tests for Futures Prices Using Jackknife Approach(1975-2006)

Commodity	Return Horizon (k-days)	Variance Ratio	<i>t</i> -statistic
KBCT Wheat	2	1.024	1.148
	5	1.000	-0.004
	10	1.013	0.241
	20	1.012	0.153
CBOT Wheat	2	1.010	0.571
	5	0.969	-1.130
	10	0.944	-1.528
	20	0.898	-1.650
CBOT Corn	2	1.036	1.723
	5	1.056	1.986
	10	1.069	1.532
	20	1.147	1.996
CBOT Soybean	2	1.005	0.270
	5	1.011	0.399
	10	0.999	-0.037
	20	1.071	1.128

Note: July observations are deleted.

t-critical value with 30 degrees of freedom at 5% significance level is 2.042.

* indicates significance at 5% level.

CHAPTER II

CAN REAL OPTION VALUE EXPLAIN WHY PRODUCERS APPEAR TO STORE TOO LONG?

Introduction

Some studies show that producers store longer than is profitable (Anderson and Brorsen 2005; Hagedorn et al. 2005). One possibility is that producers store crops longer than makes economic sense due to myopic loss aversion, which means that producers get more disutility from a loss than they get utility from receiving an equally sized gain. An alternative explanation results from producers' decisions to sell grain being irreversible. Fackler and Livingston (2002) show that this irreversibility can create a real option value from waiting to sell grain. The key to generating a real option value is for prices to follow a mean reverting process. In the case of grain as considered by Fackler and Livingston (2002), if grain prices are low it makes sense to wait to sell because prices will revert to the mean. If prices are unusually high, it is best to sell. If prices are near the mean, there can be a real option value from waiting because there is the opportunity to wait and select a time to sell when prices are higher than currently.

There are some recent studies that implement real options in agriculture. Purvis et al. (1995) examine the technology adoption of free-stall dairy housing under

irreversibility and uncertainty and find that there can be a return to waiting to adopt in some cases. Ekboir (1997), Winter-Nelson and Amegbeto (1998), and Khanna et al. (2000) also used real options to analyze the investment decision of producers under uncertainty.

This research focuses on answering the question, “Can real option values explain why producers appear to store too long?” To answer this question, this study first models and estimates the price process. The model attempts to capture two important features of agricultural commodity prices: mean reversion and seasonality. The price process which is modeled in this study differs from Fackler and Livingston (2002). The price process used here allows price to be a random walk within a season, but mean reverting across crop years. After estimating the price process, a universal lattice model is used to determine the cutoff price at which the producer is indifferent between selling and holding a crop. Simulations using cash prices of wheat, corn, and soybean are used to determine net returns under two different price processes, which is simple mean reversion and the new seasonal mean reversion price process. This empirical work shows that real option values cannot explain why producers appear to store too long.

Theory

A producer who holds stocks can be viewed as holding an American option since the producer has the option to sell at any time. The optimal storage problem is equivalent to the optimal stopping problem of an American call option which is exercised at the current price. If selling stock is irreversible the producer does not just hold stocks but holds stocks and a call option which can be exercised at the current price. An American

option is an optimal stopping problem of determining the optimal time to exercise an option. The decision to exercise the option is the same as with financial options. The option holder exercises the option, whenever its intrinsic value, which is the value of immediately exercising the option, is greater than its total value. Because of the early exercise possibility, American options are solved as a dynamic programming problem.

Our derivation is based on risk neutral valuation rather than riskless arbitrage as in Black and Scholes (1973). The typical American call option under risk neutral evaluation can be expressed in terms of a value function, V_t :

$$(2.1) \quad V_t = E[\max_{h \in T-t}(0, (p_{t+h} - X)e^{-rh})]$$

where p_{t+h} is the price of the underlying asset at time $t + h$, r is the riskfree interest rate, and X is the exercise price.

The optimal storage problem differs from (2.1). First, holding stocks of a commodity incurs positive holding charges, whereas holding an option does not incur holding cost. Second, the exercise price of the optimal storage problem is current market price, which is not discounted as in (2.1). Finally, the storage problem has an initial price which is the current cash price whereas a usual American option does not have an initial value and so the option value is zero if the option is not exercised. Then, the value function of the optimal storage problem can be defined as

$$(2.2) \quad V_t = p_t + E[\max_{h \in T-t}(0, p_{t+h}e^{-(r+s)h} - p_t)] = E[\max_{h \in T-t}(p_t, p_{t+h}e^{-(r+s)h})]$$

where p_t is cash price of a commodity at time t , T is the expiration date, and s is a per period storage cost which is a percentage of price. The producer sells stocks under the condition that

$$(2.3) \quad p_t \geq E[\max_{h \in T-t} (p_{t+h} e^{-(r+s)h})]$$

That is the producer sells stocks whenever the expected return to store and sell at time $t + h$ is less than or equal to the current market price.

Data

The chosen agricultural commodities are corn, soybeans and wheat. Thursday cash prices of South Central Illinois corn and soybean data from the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA) are obtained from a computer database compiled by Farmdoc, University of Illinois at Urbana-Champaign (2008). Thursday cash prices of wheat at Medford, Oklahoma, are obtained from the Oklahoma Market Reports of USDA. The sample period extends from October 1975 through September 2007 for corn and soybeans, and from June 1975 through May 2007 for wheat. These primary data have some missing values for Thanksgiving and Christmas season. For these missing data, the most recently observed data are used.

Annual state average prices from the National Agricultural Statistics Service (NASS) are obtained from the United States Department of Agriculture (USDA) website (2008). To estimate the price processes, 5-year moving averages of annual average prices for each crop are used as mean prices.

Corn and soybean storage costs from 1995 through 2004 are from Irwin et al. (2006). We calculate the previous 20 years of storage costs from 1975 to 1994 using producer price index from website of United States Department of Labor, and assume that storage costs of 2005 and 2006 equal the cost of 2004. Storage costs of wheat from 1975

to 2006 are obtained from Oklahoma Cooperative Extension Service at Oklahoma State University. The interest cost is calculated at the prime rate for that year plus 2%. The prime rate is the prime charged by banks in June for that year, quoted from the Kansas City Federal Reserve Bank (2008).

Procedures

Three main procedures are used: estimation of price process parameters, determining cutoff price, and simulation of the trading rules. A universal lattice model (Chen and Yang 1999) and discrete stochastic dynamic programming are used to determine cutoff prices.

Estimation of Price Process Parameters

The model of prices used here attempts to capture two important features of agricultural commodity prices, mean reversion and seasonality. A number of studies documented mean reversion in commodity cash prices (Brennan 1991; Lence et al. 1993; Dixit and Pindyck 1994; Bessembinder et al. 1995; Wang and Tomek 2007). Also, some other studies have found that futures prices follow a near random walk within a contract month (Bessler and Covey 1991; Yoon and Brorsen 2005), but are mean reverting when prices across multiple contract months are used (Schroeder and Goodwin 1991).

Seasonality in the mean level of price has been also well documented in commodity. For example, prices of seasonally produced goods tend to rise during the marketing season to cover the cost of storage. Price process in this research is not focused on seasonal volatility but on seasonal mean reversion. While seasonal volatility

is statistically significant due to the large sample size, it is relatively small and is not included here to simplify the model. A price process model which represents mean reversion can be described by

$$(2.4) \quad \ln p_t - \ln p_{t-1} = a_t + \beta(\ln \bar{p}_t - \ln p_t) + \varepsilon_t$$

where p_t indicates the cash price at time t , \bar{p}_t is the seasonal mean price, a_t is a seasonal function, t represents number of weeks after harvest, β is a parameter to be estimated, and ε_t is a normally distributed error term with zero mean and constant variance σ^2 . We allow prices to follow a random walk within a season, but to be mean reverting across crop years. Such a price process can be rewritten as

$$(2.5) \quad \ln p_t - \ln p_{t-1} = \begin{cases} a_t + \varepsilon_t & \text{if } t < t_0 \\ a_t + \beta(\ln \bar{p}_t - \ln p_t) + \varepsilon_t & \text{if } t \geq t_0 \end{cases}$$

where t_0 is a time within a season when the mean reverting process begins. Equation (2.5) imposes a random walk with drift in the early part of the storage season. This assumption is tested by estimating a more general model:

$$(2.6) \quad \ln p_t - \ln p_{t-1} = \begin{cases} a_t + \alpha(\ln \bar{p}_t - \ln p_t) + \varepsilon_t & \text{if } t < t_0 \\ a_t + (\alpha + \beta)(\ln \bar{p}_t - \ln p_t) + \varepsilon_t & \text{if } t \geq t_0 \end{cases}$$

Restricting α to be zero gives equation (2.5).

We find no evidence of differences among fourth, fifth, and sixth power polynomial functional forms. Visual inspection of a fifth power polynomial seasonality function suggests that it is more realistic than the other powers or a sinusoidal function. Therefore, we adopt a fifth power polynomial functional form for the seasonal function, a_t , which is

$$(2.7) \quad a_t = \sum_{i=0}^5 \gamma_i t^i$$

where the γ s are the parameters to be estimated.

If we impose a continuity restriction on the seasonal function $a(t)$ then the change of seasonality at harvest in the current year is equivalent to the change of seasonality at harvest next year. Since this study uses weekly cash price data, we can impose a continuity condition, $a_0 = a_{52}$. Using (2.7) this can be rearranged as

$$(2.8) \quad \gamma_1 = \frac{-\sum_{i=2}^5 \gamma_i (52)^i}{52}$$

and then, γ_1 can be obtained by other estimated parameters.

Equation (2.6) is estimated using cash prices of three crops – wheat, corn, and soybean and the coefficient α is not significantly different from zero (table II–1).

Therefore, α is restricted to be zero and then (2.6) can be rewritten as

$$(2.9) \quad \ln p_t - \ln p_{t-1} = \begin{cases} a_t + \varepsilon_t & \text{if } t < t_0 \\ a_t + \beta(\ln \bar{p} - \ln p_t) + \varepsilon_t & \text{if } t \geq t_0, \end{cases}$$

and then we can also define the simple mean reversion price process as

$$(2.10) \quad \ln p_t - \ln p_{t-1} = a_t + \beta(\ln \bar{p} - \ln p_t) + \varepsilon_t.$$

The specified value of t_0 can be determined by substituting numerical values from 0 to 51 for t_0 and selecting the one which gives the highest log likelihood value. Since this study uses a 5 year moving average as mean price \bar{p} , the model is not stationary. If cost of production data had been available to use instead of the 5-year moving average, the model would be stationary.

The standard errors on the computer print out in this case are conditional

standard errors and are valid conditional on the true value of t_0 being selected and no standard errors are provided for t_0 . Therefore, a nonparametric bootstrap is used to obtain estimates of standard errors of t_0 . Ten thousand samples of size 1,738 for wheat, 1,639 for corn, and 1,637 for soybean are resampled and used to estimate the parameters.

A Universal Lattice Model

While the terms used in the option pricing literature are quite different than the dynamic programming terminology used by Fackler and Livingston (2002), the approaches are equivalent in that pricing an American option requires solving a stochastic dynamic program. There are many models for pricing options. Black and Scholes (1973) developed an option pricing model for European options. Cox et al. (1979) developed the binomial option pricing lattice which is widely used within finance to price American type options as it is easy to implement and handles American options relatively well. However, the binomial model assumes that the option price can just either go up or down over a time step. It does not assume that the price may remain unchanged. In 1996, Boyle introduced the trinomial option pricing model, which is similar to the binomial method in that it employs a lattice type method for pricing options. The trinomial method is more accurate than the binomial one and gives the same results as the binomial one with a fewer steps.

In the trinomial lattice, the branches are up, flat, and down by an increment of change in underlying value Δp . That is,

$$(2.11) \quad p_{3,i,t} = p_{i,t} + \Delta p$$

$$p_{2,i,t} = p_{i,t}$$

$$p_{1,i,t} = p_{i,t} - \Delta p$$

Figure 1 shows an example trinomial lattice. The branches are down, flat, and up with the risk neutral probabilities R_1 , R_2 , and R_3 , respectively, which satisfy the following three equations

$$(2.12) \quad R_{1,i,t} p_{1,i,t} + R_{2,i,t} p_{2,i,t} + R_{3,i,t} p_{3,i,t} = p_{i,t} + \mu_{i,t}$$

$$R_{1,i,t} (p_{1,i,t})^2 + R_{2,i,t} (p_{2,i,t})^2 + R_{3,i,t} (p_{3,i,t})^2 - (p_{i,t} + \mu_{i,t})^2 = \sigma_{i,t}^2$$

$$R_{1,i,t} + R_{2,i,t} + R_{3,i,t} = 1$$

where $p_{i,t}$ is the i th node of p at time t , $p_{n,i,t}$ is the n -th lowest possible node at time $t + \Delta t$, and $\mu_{i,t}$ and $\sigma_{i,t}^2$ are the expected change and the variance of $p_{i,t}$ during the next time interval Δt , respectively. However, in the trinomial lattice, if there is mean reversion in the process, the risk neutral probabilities of all nodes in the lattice could be negative. To solve this problem, Hull and White (1990) propose four alternative branching schemes. These alternatives include the branches of the lattice to go three ups, two ups, and one up; two ups, one up, and flat; flat, one down, and two downs; and one down, two downs, and three downs. Chen and Yang (1999) argue that in the alternative trinomial lattice there seems to be no consistent way to construct the lattice in which all probabilities are guaranteed to be positive. Thus, they extend Hull and White's (1990) model and propose a general form of alternative branching schemes. This study uses Chen and Yang's (1999) universal lattice model to determine real option value.

With Chen and Yang's lattice model, the three branches can be written as

$$(2.13) \quad p_{3,i,t} = p_{i,t} + (j + k)\Delta p$$

$$p_{2,i,t} = p_{i,t} + (j)\Delta p$$

$$p_{1,i,t} = p_{i,t} + (j-k)\Delta p$$

where the variable j and k provide flexibility for the branches to yield non-negative probabilities with any level of mean and variance, respectively. With this branching method, the risk neutral probabilities can be obtained solving (2.12) and then the results are

$$(2.14) \quad R_{1,i,t} = \frac{(j\Delta p - \mu_{i,t})(j+k)\Delta p - \mu_{i,t} + \sigma_{i,t}^2}{2k^2\Delta p^2}$$

$$R_{2,i,t} = 1 - \frac{(\mu_{i,t} - j\Delta p)^2 + \sigma_{i,t}^2}{k^2\Delta p^2}$$

$$R_{3,i,t} = 1 - R_{1,i,t} - R_{2,i,t}.$$

To guarantee the convergence of the model, the constraints of $0 \leq P_{n,i,t} \leq 1$

translate into the following two sets of sufficient conditions:

$$(2.15) \quad \frac{\sigma_{i,t}}{\Delta p} \leq k \leq \frac{2\sigma_{i,t}}{\Delta p}$$

and

$$\frac{\mu_{i,t} - \sqrt{k^2\Delta p^2 - \sigma_{i,t}^2}}{\Delta p} \leq j \leq \frac{\mu_{i,t} + \sqrt{k^2\Delta p^2 - \sigma_{i,t}^2}}{\Delta p}$$

and

$$(2.16) \quad k > \frac{2\sigma_{i,t}}{\Delta p}$$

and

$$\frac{\mu_{i,t}}{\Delta p} - \frac{\sqrt{k^2\Delta p^2 - \sigma_{i,t}^2}}{\Delta p} \leq j \leq \frac{-k}{2} + \frac{\mu_{i,t}}{\Delta p} - \frac{\sqrt{k^2\Delta p^2 - \sigma_{i,t}^2}}{\Delta p} \quad \text{or}$$

$$\frac{-k}{2} + \frac{\mu_{i,t}}{\Delta p} + \frac{\sqrt{k^2 \Delta p^2 - 4\sigma_{i,t}^2}}{\Delta p} \leq j \leq \frac{k}{2} + \frac{\mu_{i,t}}{\Delta p} - \frac{\sqrt{k^2 \Delta p^2 - 4\sigma_{i,t}^2}}{\Delta p} \text{ or}$$

$$\frac{k}{2} + \frac{\mu_{i,t}}{\Delta p} + \frac{\sqrt{k^2 \Delta p^2 - 4\sigma_{i,t}^2}}{\Delta p} \leq j \leq \frac{\mu_{i,t}}{\Delta p} + \frac{\sqrt{k^2 \Delta p^2 - \sigma_{i,t}^2}}{\Delta p}.$$

Since this study assumes constant volatility, which means $k = 1$, the risk neutral probabilities and the sets of sufficient conditions for constraints of $0 \leq P_{n,i,t} \leq 1$ can be rewritten as

$$(2.17) \quad R_{1,i,t} = \frac{(j\Delta p - \mu_{i,t})(j+1)\Delta p - \mu_{i,t} + \sigma^2}{2\Delta p^2}$$

$$R_{2,i,t} = 1 - \frac{(\mu_{i,t} - j\Delta p)^2 + \sigma^2}{\Delta p^2}$$

$$R_{3,i,t} = 1 - R_{1,i,t} - R_{2,i,t}$$

and

$$(2.18) \quad \frac{\sigma}{\Delta p} \leq k \leq \frac{2\sigma}{\Delta p}$$

and

$$\frac{\mu_{i,t} - \sqrt{\Delta p^2 - \sigma^2}}{\Delta p} \leq j \leq \frac{\mu_{i,t} + \sqrt{\Delta p^2 - \sigma^2}}{\Delta p}.$$

A summary of this procedure is that Δp and Δt are chosen, and then the variable j is chosen using equation (2.18). After that, the risk neutral probabilities are obtained from equation (2.17). Finally, as mentioned in the theory section, since the optimal storage problem is equivalent to an American call option, using equation (2.2) and the value function of optimal storage problem can be determined as

$$(2.19) \quad V_t = E[\max_{h \in T-t} \{ (R_{1,t+h} p_{1,t+h} + R_{2,t+h} p_{2,t+h} + R_{3,t+h} p_{3,t+h}) e^{-(r+s)h} - p_t, 0 \}]$$

Then the cutoff price, which is the current market price where producer sells stocks since the expected return to store and sell at time $t + h$ is less than or equal to the current market price, can be determined by

$$(2.20) \quad C_t = [p_t : p_t = E\{\max_{h \in T-t} (R_{1,t+h} p_{1,t+h} + R_{2,t+h} p_{2,t+h} + R_{3,t+h} p_{3,t+h}) e^{-(r+s)h}\}]$$

We use a universal lattice model on a grid of values in p and t to determine a cutoff price. The value function is computed for each time period beginning with 52 to 1. To determine a cutoff price, we use the average cash price at harvest over the 32-year period as an initial value for each crop (\$3.23 for wheat, \$2.38 for corn, and \$5.99 for soybeans), and assume that price increments are 15 cents for corn, 38 cents for soybean, and 20 cents for wheat. Selling at harvest is the expected profit maximizing strategy when full storage and interest costs are used. Hagedorn et al. (2005) also show that selling at harvest is the best strategy when they use full storage and interest costs. However we also consider lower costs of half of the storage and interest costs as well as full storage and interest costs to determine cutoff price. Some producers are net lenders and have their own storage (so only marginal costs would affect the decision), so such lower costs are relevant for some producers.

Simulation

Simulations are conducted to determine net returns of the optimal strategy under two different price process: mean reversion and seasonal mean reversion. For the simulations, we design two different scenarios which depend on the level of storage and

interest costs. One scenario includes full storage and interest costs and another one includes half of storage and interest cost.

Using equation (2.19), the simulations are conducted with weekly cash price data for corn, soybean, and wheat to find the first selling date of crops and value of selling the crop. Net returns for each crop year for each crop were computed using the first price that exceeds the specified cutoff price function. The net returns are computed as the value of sales less stockholding costs, discounted to the harvest time

$$(2.21) \quad \pi = p_T e^{-r(T-t)} - sT p_T e^{-r(T-t)}$$

where T is the sales date, t is the first date of the marketing season assumed to be the first weekday in June for wheat and the first weekday in October for corn and soybean, and s is a per period storage cost that is a percentage of price (table II–2).

Results

The estimated nonparametric bootstrap parameters of the seasonal mean reversion process are presented in table II–3. Mean reversion occurs late July with 3.6% weekly for corn, mid or late July with 4.2% weekly for soybean, and early or mid March with 2.3% weekly for wheat. That is, the total percentages of mean reversion for a marketing year are 28.5% for corn, 41.6% for soybean, and 32.2% for wheat.

Figures II–2 through II–4 show the shapes of seasonality for corn, soybean, and wheat, respectively. After harvest, prices for corn and soybeans rapidly increase until the beginning of December and then slowly decrease. For wheat, prices also increase rapidly after harvest until early August and then slowly decrease. These seasonal price changes turn negative in early June for corn, early July for soybeans, and early March for wheat.

Thus, the seasonal function turns negative before mean reversion begins. This clearly indicates that producers will be selling before mean reversion begins (as most of them do), so real option values do not explain why producers appear to store too long.

Optimal cutoff prices are illustrated in figures II–5 through II–10. The shapes of the graphs of the model which uses a mean reversion price process are very different from the model using a seasonal mean reversion price process. Only at extremely low prices is there ever an incentive to store to the point where seasonal mean reversion begins. Since producers would rationally sell before mean reversion begins, the real option value almost always disappears. This result contrasts with Fackler and Livingston's (2002) model, which is that if grain prices are near the mean there can be a real option valuing from waiting to sell because there is the opportunity to wait and select a time to sell when prices are unusually high. They conclude that irreversibility confers an additional return in the form of an option to sell stocks in the future. This finding of a large real option value that can explain why producers appear to store too long is not supported.

The results of simulations for corn, soybeans, and wheat are presented in tables II–4, II–5 and II–6 respectively. The difference of average net returns over the 32 years between the mean reversion model and the seasonal mean reversion model is small and the result of paired difference tests in table II–7 shows that all t -values are not significant at the 5% level except a case that include full storage and interest cost for corn. Therefore, we can conclude that there is little evidence that, for most scenarios, the net returns over 32 years between the mean reversion model and the seasonal mean reversion model are different. As Brorsen and Irwin (1996) argue, statistical insignificance is a

typical result of marketing strategy simulation studies. The difference between marketing strategies is usually small, the variation is high, and with only one observation per year, the number of observations is small. Therefore, we rely primarily on the results in table II–3 in reaching the conclusion that the seasonal mean reversion model is preferred.

Summary and Conclusion

Previous studies suggest that producers tend to store crops longer than is profitable (Anderson and Brorsen 2005). Since decisions to sell are irreversible, there can be a real option value from waiting to sell grain. This research focuses on determining whether real option values can explain longer storage

We estimate a new seasonal mean reversion price process using a nonparametric bootstrap rather than estimating a simple mean reversion price process. After estimating the price process, a cutoff price at which the producer is indifferent between selling and holding the crop is determined using a universal lattice model. Simulations are conducted to determine net returns under simple mean reversion and the new seasonal mean reversion price process.

The estimated nonparametric bootstrap parameters of the seasonal mean reversion process show that mean reversion occurs mid or late July for corn, early July for soybean, and early March for wheat. The shapes of seasonality show that the seasonal function turns negative before mean reversion begins, which suggests that real option values are relatively unimportant in determining when producers sell their grain.

The graphs of cutoff price when assuming a seasonal mean reversion price process show that producers sell before mean reversion begins except when prices are

extremely low. This result contrasts with Fackler and Livingston's (2002) conclusion that irreversibility confers an additional return in the form of an option to sell stocks in the future. Therefore their finding of a large real option value that can explain why producers store too long is not supported.

The simulation results represent that the difference of average net returns over the 32 years between the mean reversion model and the seasonal mean reversion model is very small and the result of paired difference tests conclude that there is little evidence that the net returns over 32 years between the mean reversion model and the seasonal mean reversion model are different. Based on the nonparametric bootstrap estimation of price process, we can conclude that the seasonal mean reversion model is preferred.

References

- Anderson, R.W. 1985. "Some Determinants of the Volatility of Futures Prices." *The Journal Futures Markets* 5:331–48.
- Anderson, R.W., and J.-P. Danthine. 1983. "The Time Pattern of Hedging and the Volatility of Futures Prices." *The Review of Economic Studies* 50:249–66.
- Anderson, K.B., and B.W. Brorsen. 2005. "Marketing Performance of Oklahoma Farmers." *American Journal of Agricultural Economics* 87:1265–71.
- Bessembinder, H., J.F. Coughenour, P.J. Seguin, and M.M. Smoller. 1995. "Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures Term Structure." *The Journal of Finance* 50:361–75.
- Bessler, D.A., and T. Covey. 1991. "Cointegration: Some Results on U.S. Cattle Prices." *The Journal of Financial Markets* 11:461–74.
- Black, F., and M. Scholes. 1973. "The Pricing of Option and Corporate Liabilities." *Journal of Political Economics* 81: 637–59.
- Brennan, M.J. 1991. "The Price of Convenience and the Valuation of Commodity Contingent Claims." *Stochastic Models and Option Values*. D. Lund and B. Oksendal, eds., pp. 33–71. New York: North-Holland Publishing Co.
- Brennan, M.J., and E.S. Schwartz. 1985. "Evaluating Natural Resource Investments." *The Journal of Business* 58:135–57.
- Brorsen, B.W., and S.H. Irwin. 1996. "Improving the Relevance of Research on Price Forecasting and Marketing Strategies." *Agricultural and Resource Economics Review*. 25:68–75.
- Chen, R.-R., and T.T. Yang. 1999. "A Universal Lattice." *Review of Derivatives Research* 3:115–33.
- Cox, D.R., and H.D. Miller. 1965. *The Theory of Stochastic Processes*. New York: John Wiley and Sons.

- Cox, J.C., S.A. Ross, and M. Rubinstein. 1979. "Option Pricing: A Simplified Approach." *Journal of Financial Economics* 7:229–64.
- Dixit, A.K., and R.S. Pindyck. 1994. *Investment Under Uncertainty*. Princeton, NJ: Princeton University Press.
- Ekboir, J.M., 1997. "Technical Change and Irreversible Investment Under Risk." *Agricultural Economics* 16:54–65.
- Fackler, P.L., and M.J. Livingston. 2002. "Optimal Storage by Crop Producers." *American Journal of Agricultural Economics* 84:645–59.
- Fama, E.F., and K.R. French. 1987. "Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage." *The Journal of Business* 60:55–73.
- Farmdoc, University of Illinois at Urbana-Champaign. 2008. Available at <http://www.farmdoc.uiuc.edu/marketing/cash/CashTableChart.asp>. Accessed on 15 April 2008.
- Hagedorn, L.A., S.H. Irwin, D.L. Good, and E.V. Colino. 2005. "Does the Performance of Illinois Corn and Soybean Farmers Lag the Market?" *American Journal of Agricultural Economics* 87: 1271–79.
- Hull, J., and A. White. 1990. "Valuing Derivative Securities Using the Explicit Finite Difference Method." *Journal of Financial and Quantitative Analysis* 25:87–100.
- Hull, J., and A. White. 1993. "One-Factor Interest-Rate Models and the Valuation of Interest-Rate Derivative Securities." *Journal of Financial and Quantitative Analysis* 28:235–54.
- Irwin, S.H., D.L. Good, and J.Martines-Filho and R.M. Batts. 2006. "The Pricing Performance of Market Advisory Services in Corn and Soybeans Over 1995-2004." AgMAS Project Research Report 2006-02.
- Kansas City Federal Reserve. 2008. "Bank Prime Loan." Available at http://www.federalreserve.gov/releases/h15/data/Monthly/H15_PRIME_NA.txt
- Kenyon, D., K. Kling, J. Jordan, W. Seale, and N. McCabe. 1987 "Factors Affecting Agricultural Futures Price Variance." *The Journal of Futures Markets* 7:73–92.
- Khanna, M., M. Isik, and A. Winter-Nelson. 2000. "Investment in Site-Specific Crop Management Under Uncertainty: Implications for Nitrogen Pollution Control and Environmental Policy." *Agricultural Economics* 24:9–21.

- Lence, S., K. Kimle, and M.L. Hayenga. 1993. "A Dynamic Minimum Variance Hedge." *American Journal of Agricultural Economics* 75:1063–71.
- McDonald, R.L., and D.R. Siegel. 1986. "The Value of Waiting to Invest." *The Quarterly Journal of Economics* 101:707–27.
- Oklahoma Cooperative Extension Service, Oklahoma State University, 2007. Electronic database, Stillwater, OK.
- Pruvis, A., W.G. Boggess, C.B. Moss, and J. Holt. 1996. "Technology Adoption Decisions Under Irreversibility and Uncertainty: An *Ex Ante* Approach." *American Journal of Agricultural Economics* 78:541–51.
- Schroeder, T.C., and B.K. Goodwin. 1991. "Price Discovery and Cointegration for Live Hogs." *The Journal of Futures Markets* 11:685–696.
- Streeter, D.H., and W.G. Tomek. 1992. "Variability in Soybean Futures Prices: An Integrated Framework." *The Journal of Futures Markets* 12:705–30.
- Tronstad, R., and C.R. Taylor. 1991. "Dynamically Optimal After-Tax Grain Storage, Cash Grain Sale, and Hedging Strategies." *American Journal of Agricultural Economics* 73:75–88.
- U.S. Department of Agriculture (USDA), National Agricultural Statistics Service (NASS). 2008. Available at <http://www.nass.usda.gov/QuickStats/>. Accessed on 12 February 2008.
- U.S. Department of Agriculture (USDA), Oklahoma Market Reports. 1975–2007.
- U.S. Department of Labor, Bureau of Labor Statistics. (2008) Producer Price Index. Available at <http://data.bls.gov/cgi-bin/surveymost>. Accessed on 30 June 2008.
- Winter-Nelson, A., and K. Amegbeto, 1998. "Option Values to Conservation and Agricultural Price Policy: Application to Terrace Construction in Kenya" *American Journal of Agricultural Economics* 80:409–18.
- Yoon, B.-S., and B.W. Brorsen. 2005. "Can Multiyear Rollover Hedging Increase Mean Returns?" *Journal of Agricultural and Applied Economics* 37:65–78.

Table II–1. Parameter Estimate α of Seasonal Mean Reversion Price Process

Commodity	α	-2 Log-likelihood		Likelihood Ratio Test Statistic
		Unrestricted	Restricted	
Corn	0.0057	-6275.35	-6273.31	2.04
Soybean	0.0021	-6540.40	-6539.81	0.59
Wheat	0.0005	-6772.46	-6772.45	0.01

Note: χ^2_1 critical value at 5% significance level is 3.841.

Estimated unrestricted model is

$$\ln p(t) - \ln p(t-1) = \begin{cases} a(t) + \alpha(\ln \bar{p} - \ln p(t)) + \varepsilon(t) & t < t_0, \\ a(t) + (\alpha + \beta)(\ln \bar{p} - \ln p(t)) + \varepsilon(t) & t \geq t_0. \end{cases}$$

Estimated restricted model is

$$\ln p(t) - \ln p(t-1) = \begin{cases} a(t) + \varepsilon(t) & t < t_0, \\ a(t) + \beta(\ln \bar{p} - \ln p(t)) + \varepsilon(t) & t \geq t_0. \end{cases}$$

Table II–2. Per Period Storage Costs (Percentage of Price)

Year	Commodities	
	Corn and Soybean	Wheat
1975	0.0021	0.0035
1976	0.0022	0.0035
1977	0.0024	0.0042
1978	0.0026	0.0049
1979	0.0028	0.0049
1980	0.0032	0.0053
1981	0.0036	0.0056
1982	0.0038	0.0056
1983	0.0039	0.0060
1984	0.0041	0.0060
1985	0.0042	0.0060
1986	0.0043	0.0060
1987	0.0044	0.0060
1988	0.0046	0.0060
1989	0.0048	0.0060
1990	0.0051	0.0060
1991	0.0053	0.0060
1992	0.0055	0.0060
1993	0.0057	0.0060
1994	0.0058	0.0060
1995	0.0060	0.0060
1996	0.0060	0.0060
1997	0.0060	0.0060
1998	0.0060	0.0060
1999	0.0060	0.0060
2000	0.0060	0.0060
2001	0.0060	0.0070
2002	0.0060	0.0070
2003	0.0060	0.0070
2004	0.0060	0.0070
2005	0.0060	0.0070
2006	0.0060	0.0070

Table II–3. Parameter Estimates of Seasonal Mean Reversion Price Process by Nonparametric Bootstrapping

	Corn		Soybean		Wheat	
	Coefficient	Standard Deviation	Coefficient	Standard Deviation	Coefficient	Standard Deviation
α	0.0356	0.0117	0.0416	0.0194	0.0230	0.0115
γ_0	-0.0060	0.0034	-0.0037	0.0029	-0.0078	0.0037
γ_2	-5.7E-04	1.3E-04	-2.7E-04	1.4E-04	-1.4E-04	1.5E-04
γ_3	2.8E-05	6.8E-06	1.3E-05	7.3E-06	-2.5E-06	7.0E-06
γ_4	-5.8E-07	1.5E-07	-2.7E-07	1.6E-07	2.9E-09	1.5E-07
γ_5	4.4E-09	1.2E-09	2.1E-09	1.2E-09	-2.3E-10	1.1E-09
σ^2	0.0013	8.0E-05	0.0011	5.9E-05	0.0012	6.5E-05
t_0	44	6.1469	42	7.2619	38	10.8677

Note: Estimated model is

$$\ln p_{t+1} - \ln p_t = \begin{cases} f(t) + \varepsilon_{t+1} & \text{if } t < t_0, \\ g(t) + \alpha(\ln \bar{p} - \ln p_t) + \varepsilon_{t+1} & \text{if } t \geq t_0. \end{cases}$$

Table II–4. Sales Dates and Net Returns for Corn

Year	Sale Dates (Weeks from Harvest)				Per Bushel Net Returns (\$/bu)			
	Scenario 1		Scenario 2		Scenario 1		Scenario 2	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
1975	0	17	0	32	2.61	2.31	2.61	2.46
1976	15	17	20	32	2.27	2.17	2.24	2.05
1977	27	17	33	32	2.13	1.91	2.15	2.12
1978	25	16	32	19	2.03	1.98	2.19	2.03
1979	0	0	0	17	2.62	2.62	2.62	2.26
1980	0	0	0	16	3.05	3.05	3.05	3.08
1981	0	0	0	0	2.38	2.38	2.38	2.38
1982	0	0	15	0	2.00	2.00	2.14	2.00
1983	0	0	0	16	3.41	3.41	3.41	3.00
1984	0	0	17	15	2.68	2.68	2.46	2.46
1985	15	0	33	16	2.15	2.10	2.10	2.22
1986	34	0	37	0	1.41	1.42	1.50	1.42
1987	18	0	35	16	1.68	1.63	1.81	1.74
1988	0	0	0	16	2.68	2.68	2.68	2.36
1989	0	0	0	15	2.27	2.27	2.27	2.12
1990	0	0	0	15	2.19	2.19	2.19	2.19
1991	0	0	0	15	2.42	2.42	2.42	2.31
1992	0	0	25	16	2.06	2.06	1.96	1.92
1993	0	0	13	16	2.23	2.23	2.74	2.66
1994	0	0	17	15	1.95	1.95	2.07	2.08
1995	0	0	0	15	2.94	2.94	2.94	3.21
1996	0	0	0	15	2.90	2.90	2.90	2.49
1997	0	0	15	15	2.45	2.45	2.46	2.46
1998	14	0	34	15	1.85	1.81	1.68	1.90
1999	15	0	31	15	1.74	1.77	1.91	1.82
2000	12	0	35	14	1.88	1.63	1.45	1.95
2001	0	0	31	15	1.85	1.85	1.67	1.82
2002	0	0	0	16	2.46	2.46	2.46	2.12
2003	0	0	14	16	2.03	2.03	2.26	2.43
2004	0	0	33	16	1.76	1.76	1.68	1.72
2005	0	0	18	16	1.67	1.67	1.88	1.78
2006	0	0	0	15	2.41	2.41	2.41	3.30
32 year average					2.25	2.22	2.27	2.25

Note: Scenario1 includes storage and interest costs.

Scenario2 includes half of storage and interest costs.

Model1 assumes that price follows a mean reversion process.

Model2 assumes that price follows a seasonal mean reversion process.

Table II–5. Sales Dates and Net Returns for Soybean

Year	Sale Dates (Weeks from Harvest)				Per Bushel Net Returns (\$/bu)			
	Scenario 1		Scenario 2		Scenario 1		Scenario 2	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
1975	0	0	0	34	5.15	5.15	5.15	5.02
1976	0	0	0	29	5.95	5.95	5.95	9.37
1977	11	0	25	34	5.53	5.05	6.37	6.27
1978	0	0	0	0	6.17	6.17	6.17	6.17
1979	0	0	0	0	6.79	6.79	6.79	6.79
1980	0	0	0	0	7.51	7.51	7.51	7.51
1981	0	0	0	0	5.96	5.96	5.96	5.96
1982	0	0	15	0	5.00	5.00	5.22	5.00
1983	0	0	0	0	8.42	8.42	8.42	8.42
1984	0	0	0	0	5.77	5.77	5.77	5.77
1985	0	0	38	0	4.88	4.88	4.36	4.88
1986	0	0	36	0	4.80	4.80	4.77	4.80
1987	0	0	0	0	5.26	5.26	5.26	5.26
1988	0	0	0	0	7.89	7.89	7.89	7.89
1989	0	0	0	0	5.50	5.50	5.50	5.50
1990	0	0	0	0	6.01	6.01	6.01	6.01
1991	0	0	0	0	5.67	5.67	5.67	5.67
1992	0	0	15	0	5.17	5.17	5.31	5.17
1993	0	0	0	0	5.88	5.88	5.88	5.88
1994	0	0	0	0	5.22	5.22	5.22	5.22
1995	0	0	0	0	6.24	6.24	6.24	6.24
1996	0	0	0	0	7.25	7.25	7.25	7.25
1997	0	0	0	0	6.16	6.16	6.16	6.16
1998	0	0	40	0	4.92	4.92	3.18	4.92
1999	0	0	37	0	4.66	4.66	4.11	4.66
2000	0	0	37	0	4.73	4.73	3.80	4.73
2001	0	0	35	0	4.26	4.26	4.28	4.26
2002	0	0	0	0	5.18	5.18	5.18	5.18
2003	0	0	0	0	6.77	6.77	6.77	6.77
2004	0	0	0	0	4.98	4.98	4.98	4.98
2005	0	0	0	0	5.24	5.24	5.24	5.24
2006	0	0	0	0	5.27	5.27	5.27	5.27
32 year average					5.75	5.74	5.68	5.88

Note: Scenario1 includes storage and interest costs.

Scenario2 includes half of storage and interest costs.

Model1 assumes that price follows a mean reversion process.

Model2 assumes that price follows a seasonal mean reversion process.

Table II–6. Sales Dates and Net Returns for Wheat

Year	Sale Dates (Weeks from Harvest)				Per Bushel Net Returns (\$/bu)			
	Scenario 1		Scenario 2		Scenario 1		Scenario 2	
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
1975	0	0	0	23	2.91	2.91	2.91	3.03
1976	0	0	0	24	3.36	3.36	3.36	2.16
1977	0	0	25	23	1.92	1.92	2.21	2.26
1978	0	0	0	0	2.90	2.90	2.90	2.90
1979	0	0	0	0	3.40	3.40	3.40	3.40
1980	0	0	0	0	3.40	3.40	3.40	3.40
1981	0	0	0	0	3.83	3.83	3.83	3.83
1982	0	0	0	0	3.44	3.44	3.44	3.44
1983	0	0	0	0	3.39	3.39	3.39	3.39
1984	0	0	0	0	3.34	3.34	3.34	3.34
1985	0	0	0	0	2.89	2.89	2.89	2.89
1986	0	0	25	0	2.23	2.23	1.85	2.23
1987	0	0	0	0	2.32	2.32	2.32	2.32
1988	0	0	0	0	3.05	3.05	3.05	3.05
1989	0	0	0	0	3.77	3.77	3.77	3.77
1990	0	0	0	0	2.94	2.94	2.94	2.94
1991	0	0	0	0	2.52	2.52	2.52	2.52
1992	0	0	0	0	3.48	3.48	3.48	3.48
1993	0	0	0	0	2.63	2.63	2.63	2.63
1994	0	0	0	0	3.10	3.10	3.10	3.10
1995	0	0	0	0	3.91	3.91	3.91	3.91
1996	0	0	0	0	5.37	5.37	5.37	5.37
1997	0	0	0	0	3.73	3.73	3.73	3.73
1998	0	0	0	0	2.70	2.70	2.70	2.70
1999	0	0	27	0	2.36	2.36	1.65	2.36
2000	0	0	0	0	2.40	2.40	2.40	2.40
2001	0	0	0	0	2.88	2.88	2.88	2.88
2002	0	0	0	0	2.85	2.85	2.85	2.85
2003	0	0	0	0	2.83	2.83	2.83	2.83
2004	0	0	0	0	3.50	3.50	3.50	3.50
2005	0	0	0	0	3.03	3.03	3.03	3.03
2006	0	0	0	0	4.54	4.54	4.54	4.54
32 year average					3.15	3.15	3.13	3.13

Note: Scenario1 includes storage and interest costs.

Scenario2 includes half of storage and interest costs.

Model1 assumes that price follows a mean reversion process.

Model2 assumes that price follows a seasonal mean reversion process.

Table II–7. Paired Differences *t*-Ratios of the Mean Net Returns between Seasonal Mean Reversion and Mean Reversion Model (1975-2006)

Commodity	Include Storage and Interest Costs	Include Half of Storage and Interest Rate
Corn	-2.30*	-0.54
Soybean	-1.00	1.67
Wheat	N/A ^a	0.04

Note: *t*-critical value with 30 degree of freedom at 5% significance level is 2.042.

We calculate paired differences by subtracting the net return assuming a simple mean reversion model from a net return assuming seasonal mean reversion model.

^a A paired difference *t*-ratio for wheat of including storage and interest costs is not available since there is no difference of net returns between the two models, so variance of paired difference is zero.

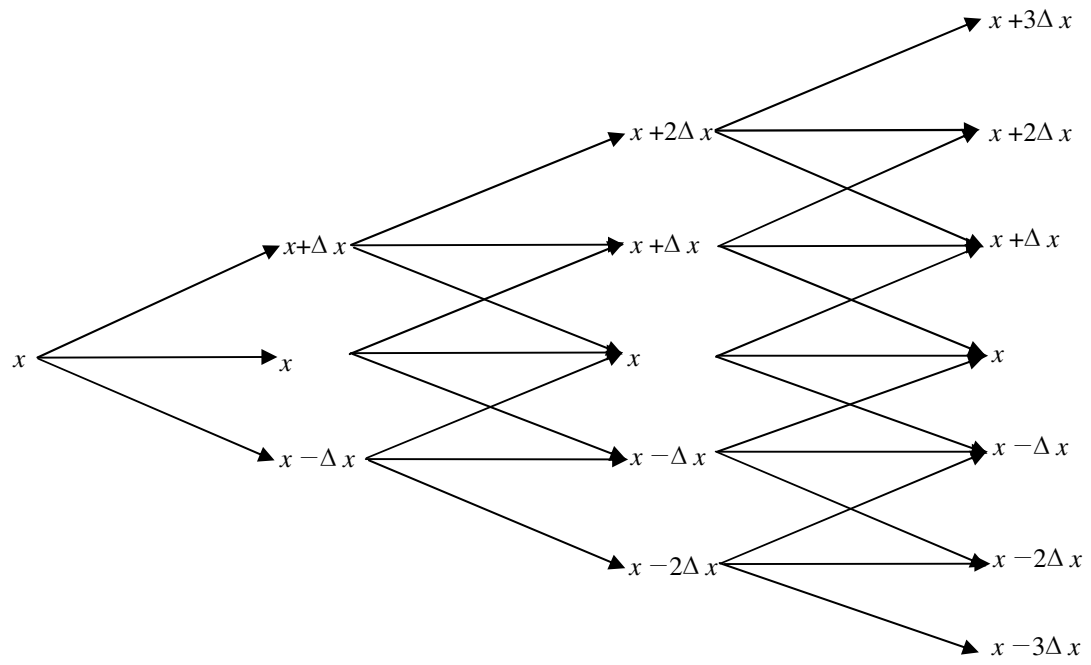


Figure II-1. An example trinomial lattice

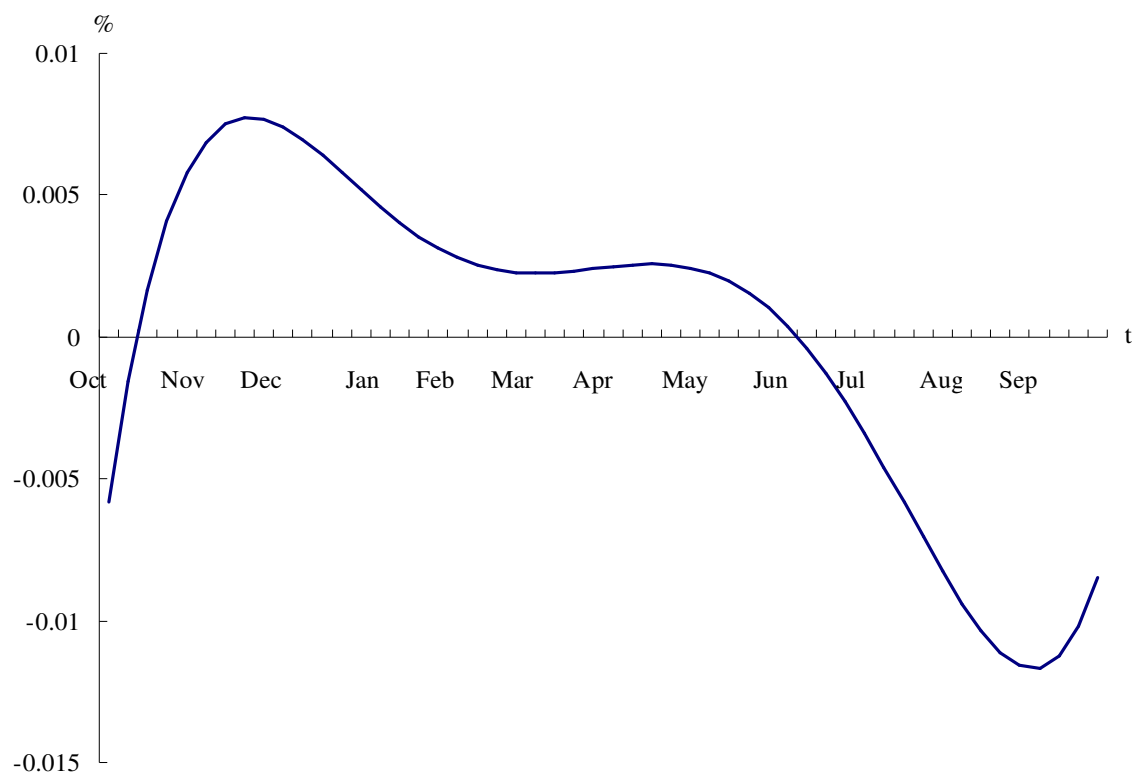


Figure II-2. Seasonality of change in corn price

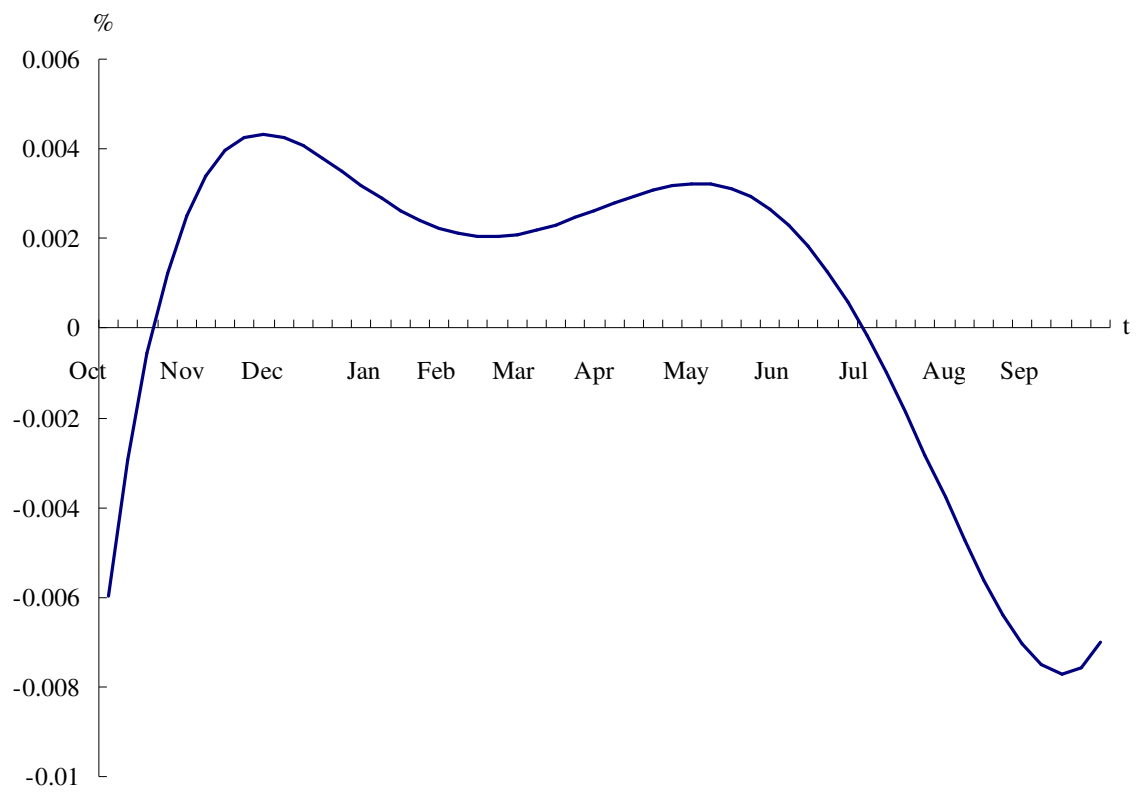


Figure II–3. Seasonality of change in soybean price

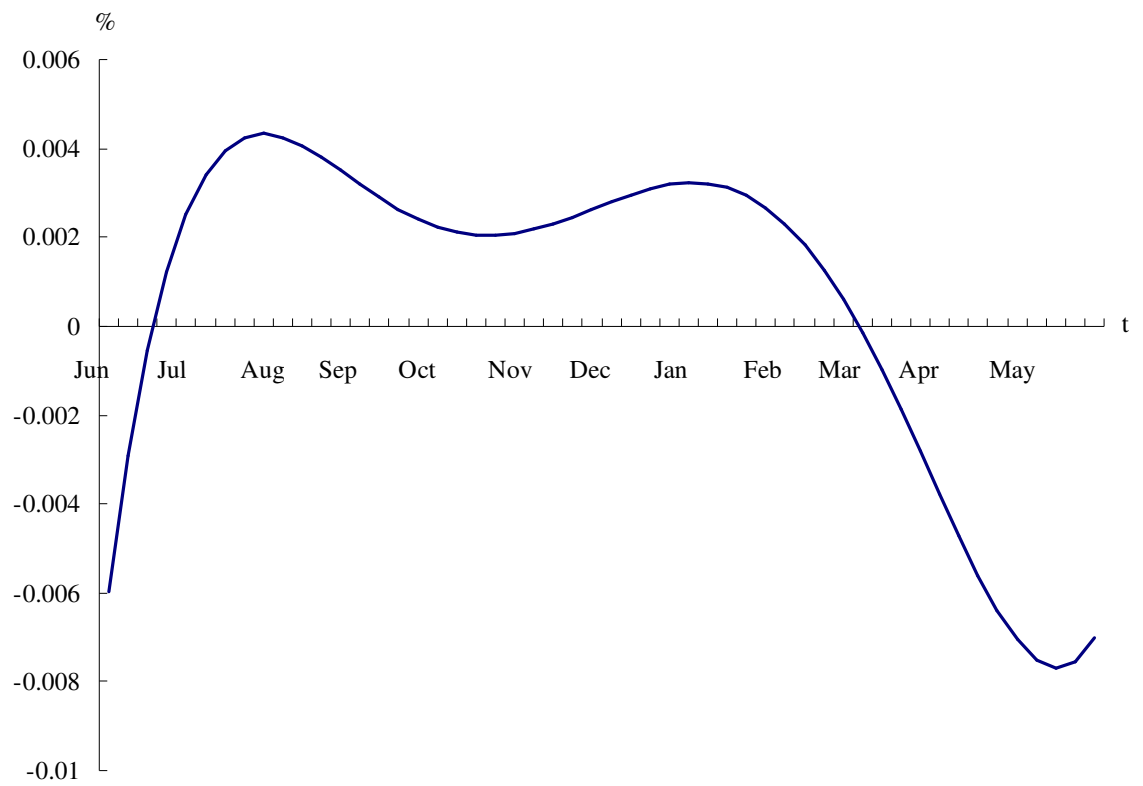


Figure II-4. Seasonality of change in wheat price

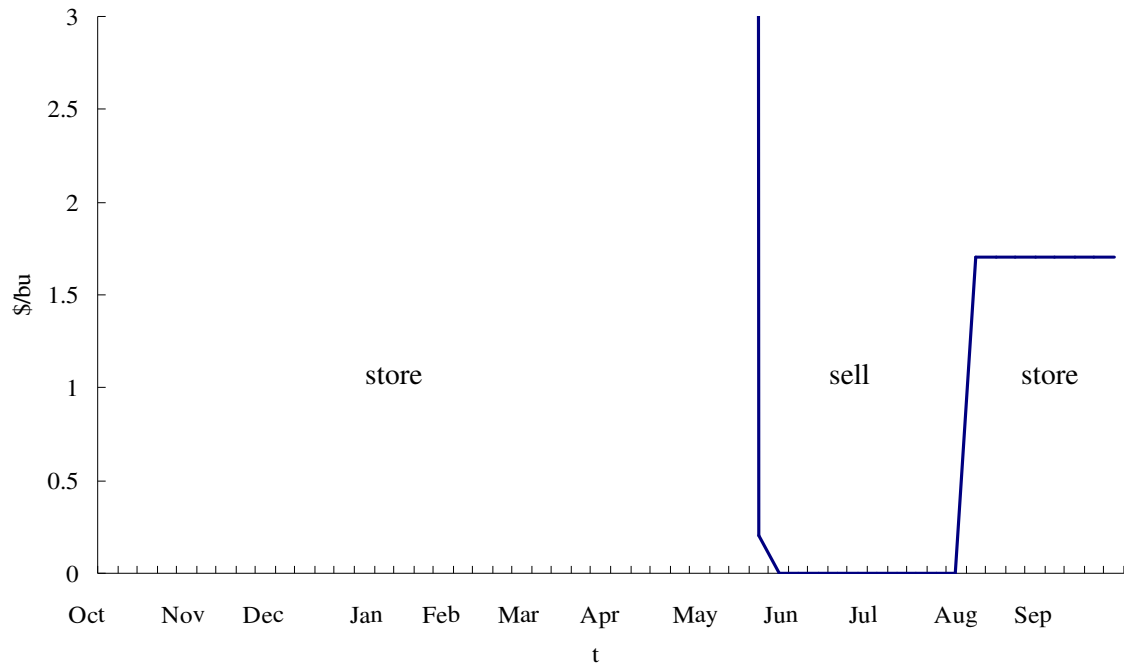


Figure II-5. Cutoff price of mean reversion price process for corn using low storage and interest costs

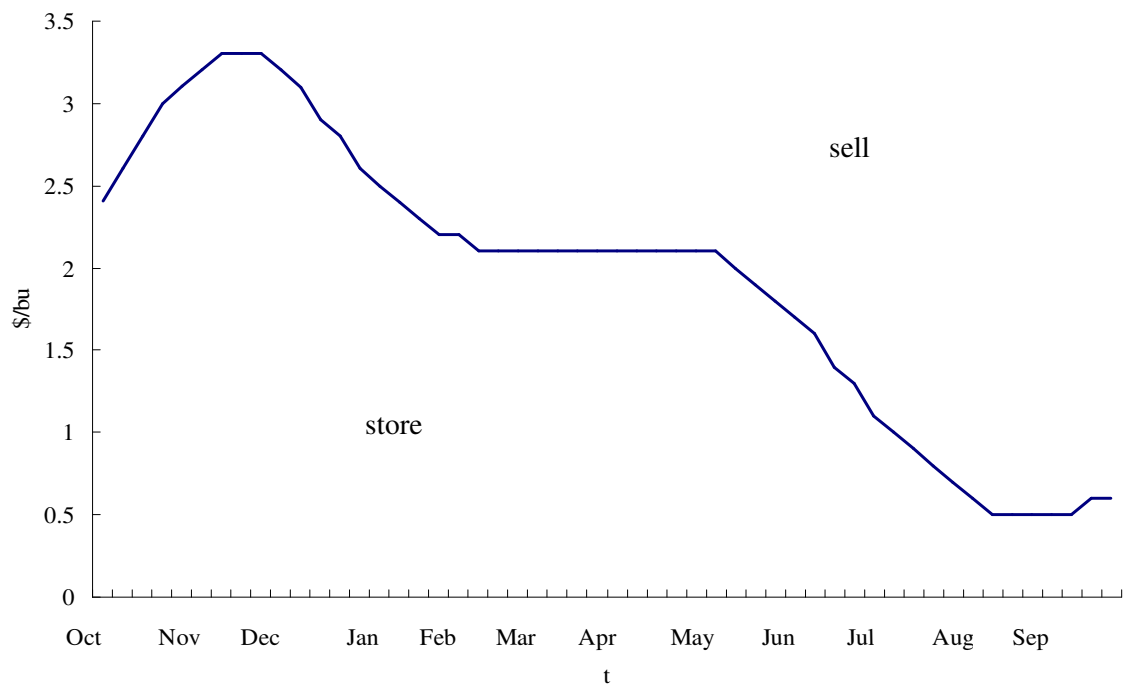


Figure II-6. Cutoff price of seasonal mean reversion price process for corn using low storage and interest costs

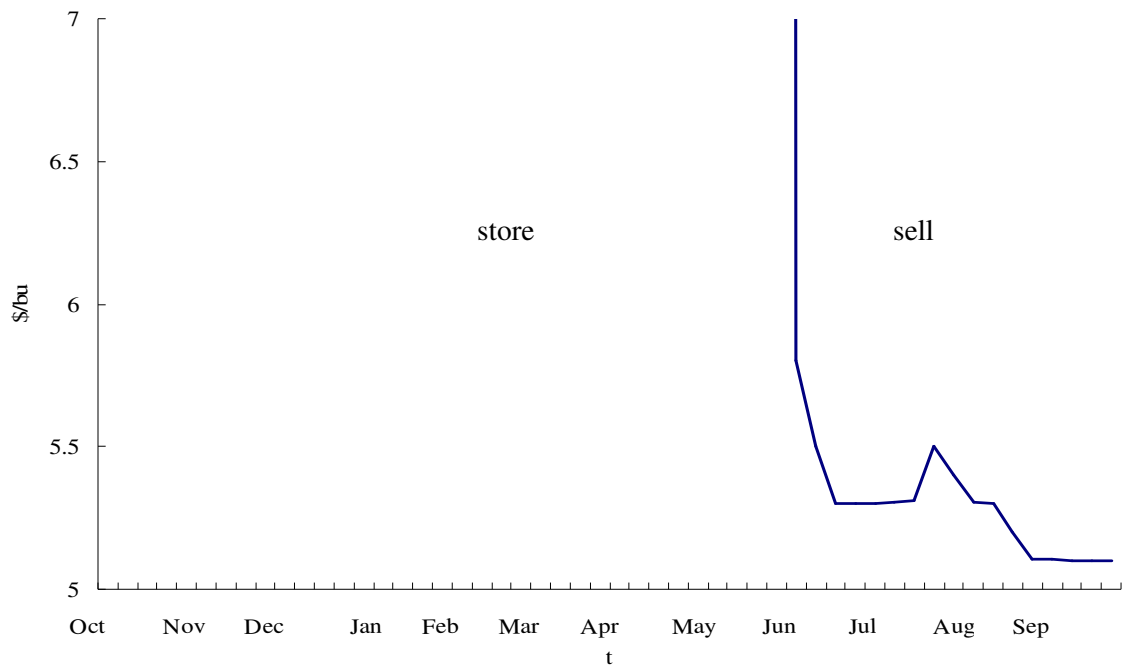


Figure II-7. Cutoff price of mean reversion price process for soybeans using low storage and interest costs

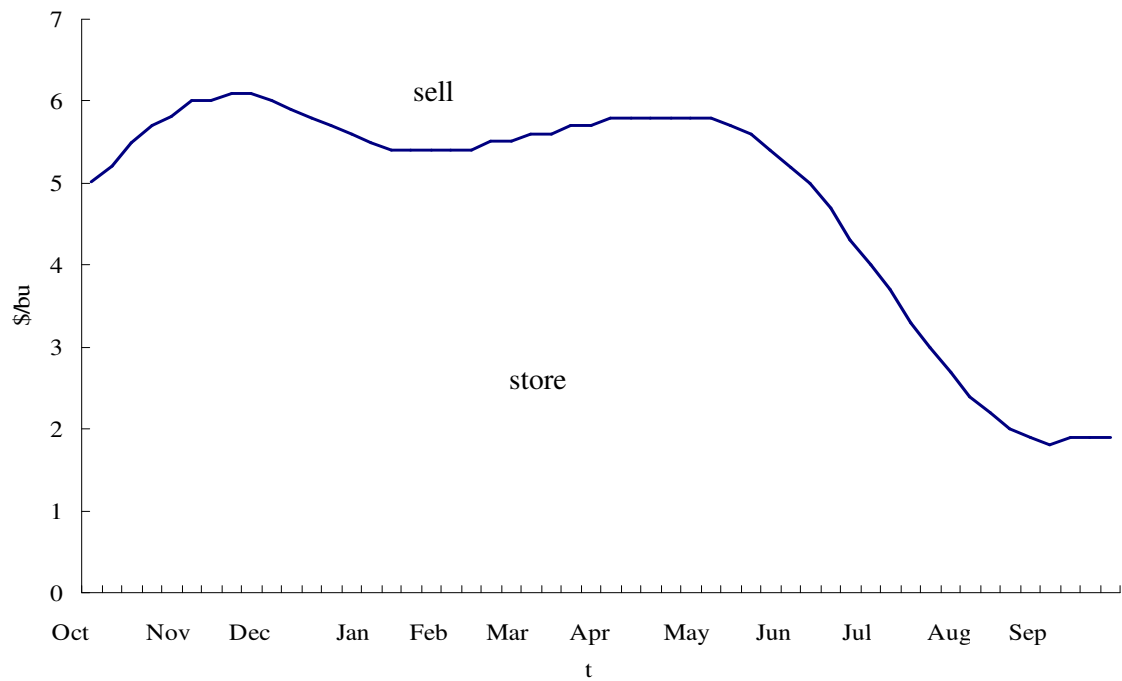


Figure II-8. Cutoff price of seasonal mean reversion price process for soybeans using low storage and interest costs

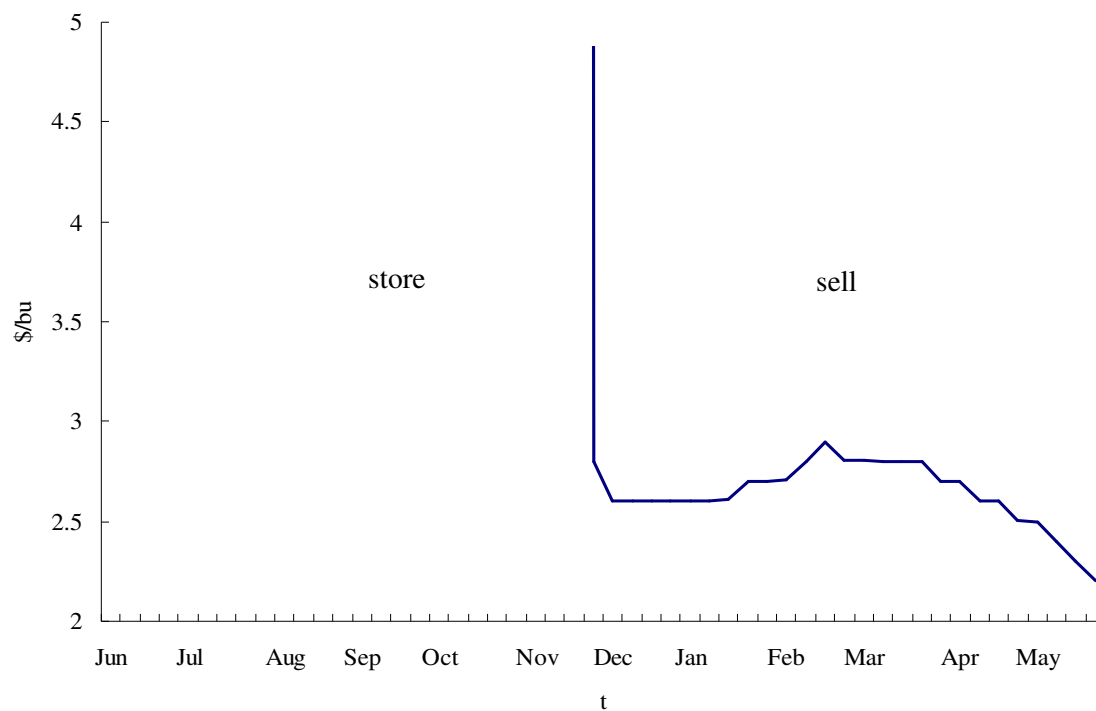


Figure II-9. Cutoff price of mean reversion price process for wheat using low storage and interest costs

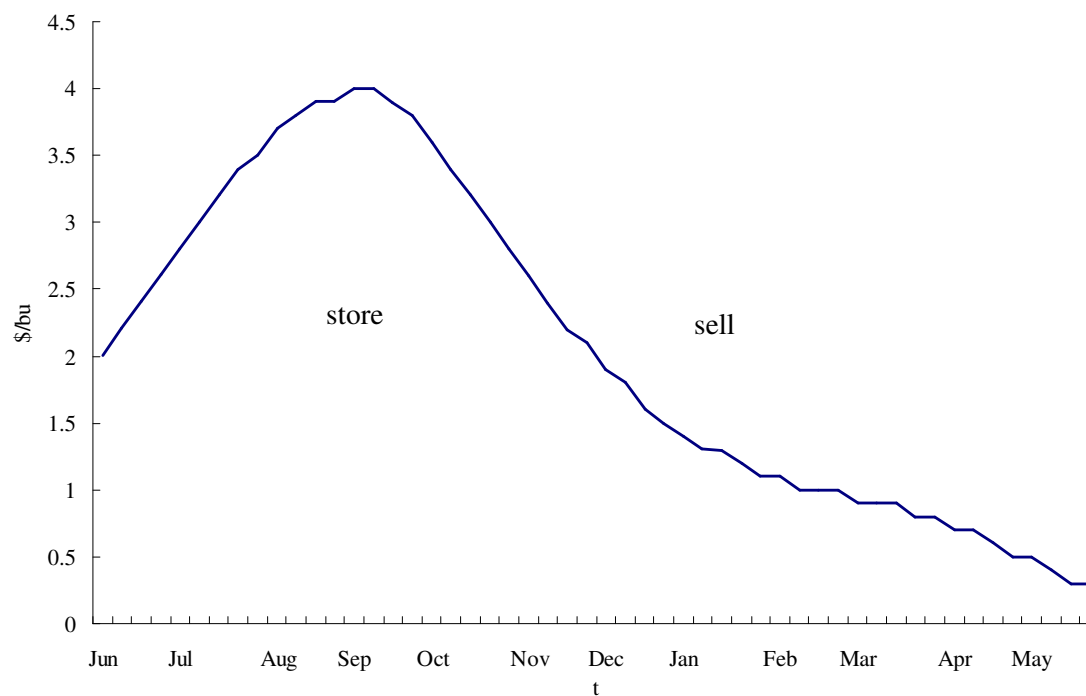


Figure II-10. Cutoff price of seasonal mean reversion price process for wheat using low storage and interest costs

VITA

HYUN SEOK KIM

Candidate for the Degree of

Doctor of Philosophy

Thesis: MAKING GRAIN PRICING DECISIONS BASED ON PROFIT MARGIN
HEDGING AND REAL OPTION VALUES

Major Field: Agricultural Economics

Biographical

Personal Data: Born in Seoul, Korea, on March 8, 1975, the son of Ho Tak Kim and Yoon Jeung Cho.

Education: Graduated from Young-Dong High School, Seoul, Korea, in February 1994; received a Bachelor of Science degree in Trade from Hankuk University of Foreign Studies, Seoul, Korea, in February 2002. Received a Master of Science degree in Agricultural Economics from Seoul National University, Seoul, Korea, in February 2004. Completed the requirements for the degree of Doctor of Philosophy in Agricultural Economics at Oklahoma State University in July 2008.

Experience: Graduate Research Assistant, Department of Agricultural Economics and Rural Development, Seoul National University, March 2002 – February 2004. Assistant Researcher, Market Analysis Team, Korean Food Research Institute, February 2004 – August 2004. Graduate Research Assistant, Department of Agricultural Economics, Oklahoma State University, August 2004 – July 2008.

Award: Spielman Scholarship for Excellence in Academic Performance, Department of Agricultural Economics at Oklahoma State University, March 2007.

Professional Membership: American Agricultural Economics Association.

Name: Hyun Seok Kim

Date of Degree: July, 2008

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: MAKING GRAIN PRICING DECISIONS BASED ON PROFIT
MARGIN HEDGING AND REAL OPTION VALUE

Pages in Study:

Candidate for the Degree of Doctor of Philosophy

Major Field: Agricultural Economics

Scope and Method of Study: This study contains two essays. The first essay is preharvest pricing decision making and the second essay is postharvest decision making. The purpose of the first essay was to determine producer's utility function and price processes where profit margin hedging is optimal. A statistical test of mean reversion in agricultural futures prices is conducted. The simulations were also conducted to compare the expected utility of profit margin hedging strategy with the expected utility of other strategies such as always hedging and selling at harvest. The purpose of the second essay was to determine whether real option values can explain why producers appear to store too long. To determine the real option value, we modeled and estimated a seasonal mean reversion price process which allowed price to be a random walk within a season, but mean reverting across crop years. After estimation of the price process, a universal lattice model was used to determine cutoff price. This study conducted simulations using cash prices of crops to determine differences of net returns of optimal strategy under two different price processes, which are a simple mean reversion price process and a new seasonal mean reversion price process.

Findings and Conclusions: Theoretical results from the first essay showed that profit margin hedging is an optimal strategy under a highly restricted target utility function even in an efficient market. Profit margin hedging is profitable if prices are mean reverting. Simulation results showed that profit margin hedging gives the highest expected utility to producers under the highly restricted target utility function. With the variance ratio test, there is little evidence that futures prices of crops follows a mean reverting process. In the second essay, the estimated nonparametric bootstrap parameters of the seasonal mean reversion process show the seasonal function turns negative before mean reversion begins, which suggests that real option values are relatively unimportant in determining when producers sell their grain. The graphs of cutoff price when assuming a seasonal mean reversion price process show that producers sell before mean reversion begins except when prices are extremely low. Therefore, Fackler and Livingston's (2002) finding of a large real option value that can explain why producers store too long is not supported. The simulation results show that there is little evidence that the net returns between the mean reversion model and the seasonal mean reversion model are different.

ADVISER'S APPROVAL: B. Wade Brorsen