

INTERTEMPORAL RISK MANAGEMENT DECISIONS OF FARMERS UNDER  
PREFERENCE, MARKET, AND POLICY DYNAMICS

By  
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To the Faculty of Washington State University:

The members of the Committee appointed to examine the dissertation of  
WEN DU find it satisfactory and recommend that it be accepted.

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Chair

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Abstract

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May 2005

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Three separate, but related chapters of this dissertation examine the risk management issues related to dynamic stochastic agricultural production, following the introduction of the whole dissertation in Chapter 1.

Chapter 2 adapts a generalized expected utility (GEU) maximization model (Epstein and Zin, 1989 and 1991) to examine the intertemporal risk management of wheat producers in the Pacific Northwest. Optimization results based on simulated data indicate the feasibility of the GEU optimization as a modeling framework. A comparison between the GEU and other expected utility models further implies GEU has the advantage of specifying farmers' intertemporal preferences separately and completely.

Based on the GEU framework, Chapter 3 examines the impacts of farmers' risk aversion, time preference, and intertemporal substitutability on their optimal risk management decisions. It further extends the GEU model by incorporating a welfare measure, the certainty equivalent, to investigate the impacts of U.S. government programs and market institutions on farmers' risk management decisions and welfare.

Results imply that farmers' optimal hedging is sensitive to changes in the preferences and the effects of these preference changes are intertwined. Target price and loan rate levels, offered by certain government payment programs, can lead to the substitution of government programs for hedging. The evaluation of current risk management tools shows both crop insurance and government payments can improve farmers' welfare significantly. Government payment programs have a greater effect on farmers' welfare than crop insurance and crop insurance outperforms hedging.

Chapter 4 explores the market integration of Chinese wheat futures to the world. It compares the price behavior of China Zhengzhou Commodity Exchange (CZCE) with that of the Chicago Board of Trade (CBOT) in the US using ARCH/GARCH-based univariate and multivariate time series models and cointegration analysis. Results show both markets can be modeled by ARCH(1)/GARCH(1,1) and the models have a better fit when the conditional error variance is  $t$  distributed. The price series in CZCE and CBOT are interrelated but not cointegrated. The existing interrelations between the two markets are significant and asymmetric. CBOT holds a dominant position in the interactions while CZCE behaves like a follower.

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## **Dedication**

This dissertation is dedicated to my parents Dehua Weng and Chenglin Du,  
my husband Weiya Zhang, and my brother Hao Du,  
who have always loved and believed in me.

# CHAPTER 1

## INTRODUCTION

### I. Discussion of Primary Issues

Risk and instability are inherent for farm income due to unpredictable weather, the biological nature of agricultural production, technology advancement, and price fluctuation in commodity markets. Risk management becomes critical for modern farms with larger acreage, more machinery, and more reliance on debt financing. In the meantime, the development of risk management instruments, especially in the past twenty years, has provided farmers with more options and flexibility to reduce risk and secure income.

Among available risk management tools, commodity futures is a traditional tool in the market to manage price risks; government-sponsored crop insurance is currently the most popular risk management tool that helps reduce yield and revenue risks for farmers in the US; and government programs provide various payments that work as price insurance but with a zero premium. Despite that, the risk management effectiveness and farmers' participation incentives have always been a concern (Brosen, 1995; Ke and Wang, 2002).

The risk management situation in the Pacific Northwest (PNW) provides us with an interesting case to explore farmers' risk management decisions in this area. The PNW, covering Washington, Idaho, California, and Oregon, is one of the major wheat production areas in the US. There is a large acreage of non-irrigated farms in this region. Soft white winter wheat has been the dominant cash crop and is primarily exported to the Asian market. This region, however, has

historically been an area with low utilization rates of risk management instruments like futures (Makus, *et al.*, 1990) and some acreage-based crop insurance (Vandever and Young, 2000).

Current research progress in the modeling of farmers' risk management strategies is centered on examining risk management instruments and primarily based on static models. However, agricultural production is a continuous dynamic process and the decisions on risk management strategies (government programs for example), have a multi-period impact. Thus, intertemporal dynamic models seem more appropriate for analyzing farmers risk management decisions. Among the aforementioned risk management instruments, most have been investigated separately with a vast amount of literature. Recently research has started to favor a portfolio approach to investigate farmers' use of these instruments.

For dynamic programming, time-separable expected utility (EU) maximization is a standard framework in past studies, especially agricultural risk analysis (Huffaker, 1998). Despite the fact that EU has shown feasibility as a dynamic modeling framework, its specification assumes utility is additively separable and therefore implies the decision maker is intertemporally risk-neutral. This could be a strong restriction for farmers who use the entire time span of farm management as a continuum to fulfill their long-run goal of maximizing utility and minimizing risk.

A primary goal of the dynamic risk management part of this dissertation is to develop a dynamic modeling framework that is suitable to study farmers' risk management decisions in a multiple-year production environment. Once an appropriate model is identified, the focus moves on to investigate and evaluate different risk management portfolios that are applicable to farmers' intertemporal decisions.

The third part of this dissertation is dedicated to price analysis in wheat futures markets. Unlike crop insurance and government payments, futures price is totally determined by market forces and open to all farmers. When the futures market is efficient, it provides an effective channel for farmers to reduce potential loss due to future price fluctuations in the spot market. A well-established commodity futures market is influential not only to agricultural production but also to a country's food security and price system.

The Chicago Board of Trade (CBOT) in the US is by far the world largest and most developed agricultural commodity exchange. Wheat futures trading has been in CBOT for more than a hundred years. The CBOT wheat futures price is now the main price indicator in the world wheat market. As the world largest wheat producer and consumer, China had its wheat futures trading established in the China Zhengzhou Commodity Exchange (CZCE) in 1993. Since establishment, the CZCE has been following the organizational structure and management of CBOT. The CBOT wheat futures prices were perceived influential to the price behavior of wheat futures in CZCE as well. The CZCE has shown high correlation in the prices with the CBOT in recent years.

China's wheat markets have entered the fast lane to international integration since November 2001, when China obtained full membership to the WTO. Integration into the world market can have a two-folded impact. The stronger linkage to the world helps bring the previously over-valued prices in China back to a reasonable level, and therefore encourages the formation of a competitive and efficient market. Meanwhile the enhanced integration introduces more unpredictable factors from the world economy into China and brings about extra instability. As the world's largest wheat trading country, China has a strong influence on the world wheat

market. Integration of the Chinese wheat market can also affect other major partners in the world market in many ways.

There is another reason for the expectation of international integration besides the structural similarity between CBOT and CZCE. It comes from the analogous fact that China's major food markets have shown strong trend in domestic market integration, after most barriers to cross-region trading and information flows were removed in recent years. Huang and Rozelle (2004) studied the emergence of China's agricultural commodity markets. Results showed that rural China now has some of the least distorted and most integrated agricultural markets in the world. Will similar trends also be detected or implied after the complete international integration of Chinese wheat futures market? Will this integration be a win-win situation for both China and the US? This dissertation includes an attempt to address these issues by an analysis of price behavior between the CZCE and CBOT.

## **II. Dissertation Structure**

This dissertation examines various risk management issues related to wheat production in the Pacific Northwest and price analysis for China and US wheat futures markets. Apart from the introductory chapter, three separate, but related papers are presented in Chapter 2 through Chapter 4. The papers respectively focus on stochastic dynamic modeling of farmers' optimal risk management in multiple year production, impact analysis of changing preferences, market institutions, and policies on farmers' risk management behavior, and price analysis and market integration in international wheat futures markets.

Chapter 2, Intertemporal Decisions of Farmers' Risk Management: A Dynamic Optimization with Generalized Expected Utility, explores farmers' intertemporal decisions of

risk management by adapting a generalized expected utility (GEU) maximization model (Epstein and Zin, 1989 and 1991) to dynamic risk analysis in Washington State wheat production. Compared with the traditional EU maximization model, this GEU model uses a recursive constant elasticity of substitution (CES) utility function. The recursive structure has a dynamic nature and the CES form makes it possible to disentangle the decision maker's intertemporal substitution preference from temporal risk aversion. This specification allows him/her to have non-neutral time preference. Particularly, the GEU model incorporates some commonly used EU models including the recursive constant elasticity of substitution EU model (CES-EU) and the standard multi-period recursive EU model (MR-EU) as special cases. Results from GEU models are compared with those from other expected utility (EU) maximization models.

Chapter 3, *The Impacts of Intertemporal Preferences, Market Institutions, and Government Policies on Farmers' Risk Management Behavior*, aims to assess the impacts of changing intertemporal preferences, market institutions, and policies on farmers' risk management behavior and welfare based on the GEU framework. A welfare measurement, the certainty equivalent (CE), is introduced to the GEU model. The CE is employed to evaluate alternative risk management portfolios relative to cash sales, in response to changes in market institutions and policy arrangements, and to various specifications of intertemporal preferences. The portfolios are constructed by different combinations of available risk management instruments including futures, farm-level yield-based multiple peril crop insurance, and the three primary government payments: direct payment (DP), loan deficiency payment (LDP), and counter-cyclical payment (CCP).

Chapter 4, *Price Behavior and International market integration: A Comparison of China and U.S. Wheat Futures*, presents a quantitative assessment of the international market



integration of Chinese wheat futures market CZCE to the world in the background of WTO through relationships in price behaviors. The CBOT is chosen to represent the world market in the analysis. Univariate analyses are used to first identify an appropriate process for the CZCE and CBOT price series. Then volatility transmission and interactions in price movements across the two markets are studied simultaneously using a bivariate model. Time series Autoregressive Conditional Heteroskedasticity (ARCH) and Generalized ARCH (GARCH) models, and Vector Autoregressive (VAR) and cointegration analysis are the major methods used in the paper. Based on relationships evident in the price behaviors, an evaluation of the extent and outlook for the Chinese wheat futures market integration into the world market under the influence of WTO is presented.

### **III. Summary of Findings**

In Chapter 2, a representative farmer is selected from Whitman County, Washington, a dryland farming region in the Pacific Northwest where soft white winter wheat is grown. Under GEU, the farmer is assumed to make the portfolio decisions upon hedging in the futures markets, purchasing crop insurance, and participating in government programs based on information available at the beginning of a period of multiple years. His or her optimal selection of a risk management portfolio is reached according to certain risk preference, time preference, and intertemporal substitutability.

A stochastic trend model, which accommodates a random walk at the mean level and a kurtotic distribution, is used to identify the long-term time series patterns of annual wheat yield, cash price, and futures price from Whitman County. Based on estimation results, cash and futures prices are simulated jointly following a stochastic trend process based on September

Portland cash price and Chicago Board of Trade futures price from 1972 to 2003. Yield data are simulated following a deterministic trend based on historical yield from 1939 to 2003.

The stochastic dynamic optimization problem is solved numerically based on simulated data for 2004 to 2008. Results show that the optimal solutions vary with model specifications and have different paths under different preference sets. When comparing the optimal solutions from the GEU, the EU models which are special cases of GEU (CES-EU, MR-EU), and a multi-period additive EU model (MA-EU)<sup>1</sup>, we find the GEU model has advantages over the EU models. The GEU model yields more reasonable hedge ratios and crop insurance coverage levels which are consistent with the specified time and intertemporal substitution preferences. It also possesses flexibility in specifying the intertemporal preferences separately and completely, which the EU models either ignore or cannot differentiate. A further examination of the EU models implies that there is possible interchangeability between the CES-EU and the MA-EU models, which could be useful for method implementation in empirical studies.

Following the same risk management problem setting, data arrangement, and the base model as in Chapter 2, Chapter 3 presents empirical results of an impact analysis of intertemporal preferences, market institutions, and policy alternatives on optimal risk management decisions.

Preference impact analysis implies that optimal hedging behavior of the representative farmer is sensitive to intertemporal preferences changes. Risk aversion appears to have a larger effect on hedge ratios than time preference and intertemporal substitution. Each of the preferences has its own pattern of impact. But even in the separate analysis, the effect is often intertwined with influences from other preferences due to relative value changes.

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<sup>1</sup> This multi-period additive EU model is an extension of the static single period EU maximization model, which is widely used in static single-period risk analysis. The model uses the standard constant relative risk aversion utility function.

The market institution impact analysis shows that hedging transaction costs negatively affect optimal hedge ratios and reduce the farmer's welfare. When crop insurance is coupled with a premium subsidy, even an insurance premium loading of 30% is insufficient to reduce the farmer's interest in purchasing the highest available level of insurance coverage. However, premium loading definitely reduces the farmer's welfare.

Impact analysis of the government price protection parameters, the target price specified in the LDP and the loan rate specified in the CCP, shows that both are influential in hedging decisions. The corresponding LDP and CCP programs have increasing substitution effect for hedging as the price protection level increases.

The relative impact analysis of current risk management tools shows both crop insurance and government programs are influential to the farmer's welfare improvement while hedging has a very limited contribution. In terms of the ranking of these tools, the government payment programs have a greater effect on the farmer's welfare than crop insurance and crop insurance outperforms hedging.

Chapter 4 finds that both CZCE and CBOT prices can be best modeled by an ARCH(1)/GARCH(1,1) process. These results are consistent with previous studies on agricultural commodity prices, and imply Chinese wheat futures prices behave in a similar way as that in the representative world market. Compared with the CBOT wheat futures price, the CZCE price has a longer memory and carries more volatility. It is also shown that the excess kurtosis problem can be lessened when the conditional distribution are t distributed. The goodness-of-fit for the models are obviously improved.

Bivariate analysis of CZCE and CBOT prices up to the end of 2001 implies the interrelations between the two markets are generally not strong and asymmetric during the pre-

WTO periods. CBOT plays a leading role in the interactions and CZCE behaves more like a follower. Price series after 2001 show, however, the two markets have gone through different trends, and the correlation between CZCE and CBOT are getting even weaker. Market integration of Chinese wheat futures relative to the world market seems diverging compared to previous expectations.

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## CHAPTER 2

### INTERTEMPORAL DECISIONS OF FARMERS' RISK MANAGEMENT: A DYNAMIC OPTIMIZATION WITH GENERALIZED EXPECTED UTILITY

**Abstract:** In this paper we attempt an intertemporal study of risk management decisions for wheat growers in the Pacific Northwest. We apply a generalized expected utility model (GEU) to examine a representative farmer's optimal choices of hedging ratios and crop insurance coverage levels in the presence of government payment programs in a multi-period production environment. A stochastic trend model is used to identify the long-term time series patterns of annual wheat yields, cash prices, and futures prices from two counties in Washington. The fitted models are then used as the base for yield and price simulation over the next five years. The stochastic dynamic optimization problem is solved numerically based on simulated data. The optimal solutions indicate that the GEU model is feasible in modeling farmers' intertemporal decisions regarding risk management. The comparison between the GEU model and some commonly used expected utility models further implies the advantage of the GEU model in being flexible to specify farmers' intertemporal preferences separately and completely.

**Keywords:** intertemporal decision, generalized expected utility, dynamic optimization, risk management

## I. Introduction

Agricultural production is a stochastic process greatly affected by unpredictable weather, technology advancement, individual farming practices, and price fluctuations in commodity markets. The risk management situation confronted by farmers is complicated with intra- and inter-temporal uncertainties in continuous multi-period production. Modeling farmers' risk management has been commonly based on a static approach, although a stochastic dynamic approach is more consistent with reality. The complexity involved in stochastic dynamic modeling is that it requires decision making to incorporate multi-dimensional uncertainties into one entirety.

Expected utility maximization, commonly used as a standard framework in many studies including agricultural risk analysis, has been shown feasible in dynamic modeling. It allows a risk averse farmer to maximize a summarized discounted von Neumann-Morgenstern expected utility function of his or her stochastic income subject to a set of policy and resource constraints. Such a specification, however, assumes utility is additively separable and therefore implies the decision maker is intertemporally risk-neutral. A generalized expected utility (GEU) maximization model, developed by Epstein and Zin (1989, 1991), provides an alternative to study intertemporal decisions with further specification of the decision maker's preferences. The model utilizes a recursive utility function of constant elasticity of substitution (CES) form as the objective function. This approach incorporates the decision maker's non-neutral intertemporal substitution preference through different levels of elasticity of substitution. In this sense the recursive model disentangles intertemporal substitutability from temporal risk aversion.

Currently, U. S. farmers are able to use several risk management tools to manage risks, and make long term strategic plans accordingly. Futures contracts are a traditional tool for farmers to hedge price risk and has been available for a long time. By selling short futures at planting time, farmers can lock in a delivered price at harvesting time, therefore reducing market price risks. Crop insurance, currently facilitated and subsidized by the US federal government, is currently the most popular tool used by U.S. crop producers to manage yield and/or price risks. Government payment programs provide direct cash compensation to farmers in bad years as a revenue protection. With increased involvement, government allocates a significant amount of tax dollars to provide and subsidize all of these programs every year. Despite that, the risk management effectiveness and farmers' participation incentives have always been a concern (Brorsen, 1995; Ke and Wang, 2002).

The objective of this paper is to apply the GEU model to farmers' intertemporal portfolio risk management decisions and compare it with the commonly used additive EU models as a framework in such decisions. The farmer's optimal risk management portfolios are examined under the GEU framework, where he/she chooses from hedging instruments, insurance products, and government payment programs to maximize utility.

Specifically, the paper proceeds as follows: 1) Section II reviews literature in agricultural risk management modeling; 2) Section III discusses the model structure; 3) Section IV introduces the data and the simulation of yields and prices; 4) Section V discusses the optimization results; and 5) Section VI summarizes and draws conclusion.



## II. Existing Literature

As a modeling framework, the expected utility (EU) maximization approach has been applied to producers' risk analysis in both static and dynamic situations since the 1970s.

However, unlike its counterparts in economics and finance, a large amount of the existing work only use EU under static scenarios in agricultural economics (Nyambane et al., 2002).

In the standard specification of intertemporal EU maximization, it is common to assume an additive and homogeneous von Neumann-Morgenstern utility index. Such a specification, however, intertwines two distinct aspects of preference, intertemporal substitutability and relative risk aversion (Epstein and Zin, 1989). Additionally, these models did not perform well in empirical examinations (Hansen and Singleton, 1983; Mehra and Prescott, 1985). As a more general framework, the GEU model uses a CES-form utility function and has a recursive structure. The CES form adds extra flexibility in identifying intertemporal substitution along the time span, and is able to disentangle the intertemporal substitution from the risk aversion.

With the possible and testable separability for risk preference and intertemporal substitutability, it is possible to use the GEU model to estimate preference parameters separately and examine the form of the objective function. Continuing on from their theoretical paper, Epstein and Zin (1991) empirically investigated the parameter estimation and the testable restrictions. Although favorable and seemingly consistent with theory, they found those estimates and test results are sensitive to consumption measures and instrumental variables. As one of the earliest agricultural economists to apply this GEU model in agricultural production, Lence (2000) used 1936-1994 U.S. farm data to study the fitness of a GEU framework and farmers' time and risk preferences. He found the estimated farmers' utility parameters satisfy the

theoretical restrictions of the GEU model. Furthermore, the EU model is rejected in favor of the GEU model. Knapp and Olson (1996) used GEU to solve dynamic resource management problems. They found intertemporal substitution has a substantial effect while risk aversion has a very small effect on optimal solutions. Howitt et al. (2002) applied a GEU framework to stochastic water supply management. The empirical results underscore the importance of using this more general specification of intertemporal preferences.

On the other hand, studies on agricultural risk management strategies have been extended from the earlier one-element models to portfolio models. They analyzed the effects of different combinations of instruments and interactions between each instrument. Among them are portfolios of crop yield insurance and futures contracts (Myers, 1988), futures market and government farm programs (Crain and Lee, 1996), crop yield insurance, futures, options and government programs (Wang, et al., 1998), and crop revenue insurance, futures and government programs (Zuniga, Coble, and Heifner, 2001; Wang, Hanson, and Black, 2003; Wang, Makus, and Chen, 2004). Government programs have been studied either singularly (Miller, Barnett, and Coble, 2001) or in a portfolio setting together with other instruments as mentioned above. The newly-added counter cyclical payment program in the 2002 Farm Bill has also been investigated (Wang, Makus, and Chen, 2004). However, all of these studies are static in nature.

### **III. Model**

#### ***Theoretical Framework***

The foundation of the GEU model for intertemporal analysis builds on the independent works of Epstein and Zin (1989, 1991), and Weil (1990). In this study we focus on Epstein and Zin's approach.

The representation of the general preference for a decision maker under risk can be identified as:

$$(2.1) \quad \text{Max} U_t = \left\{ (1 - \beta) C_t^\rho + \beta \left[ E_t \left( \tilde{U}_{t+1}^\alpha \right) \right]^\frac{\rho}{\alpha} \right\}^\frac{1}{\rho}$$

where  $U_t(\cdot)$  is the von-Neumann Morgenstern utility function indexed by time  $t$ ;  $E_t$  is the expectation operator at current period  $t$ ; the “ $\sim$ ” above  $U$  indicates the stochastic property of utility.  $\beta$  ( $0 < \beta < 1$ ) is the discount factor per period and implicitly defines the decision maker’s time preference. By consuming at  $t + 1$ , he/she only consumes a fraction ( $\beta$ ) of the utility that would have been consumed at  $t$ .  $\alpha$  ( $0 \neq \alpha < 1$ ) denotes the risk aversion parameter, and is equal to one minus the Arrow-Pratt constant relative risk aversion (CRRA) coefficient. A smaller  $\alpha$  indicates greater risk aversion.  $\rho$  ( $0 \neq \rho < 1$ ) denotes the intertemporal substitutability, equal to  $(1 - \sigma)^{-1}$  with  $\sigma$  denoting the elasticity of substitution. Early (late) resolution of risk would be preferred if  $\alpha < (>) \rho$ .  $C_t$  denotes the current consumption which is a function of the risky variables and the risk management choice variables. The decision maker’s objective function is to maximize current utility, which comprehensively incorporates all of the lifetime expected future utilities.

The recursive GEU specification enables a separation of risk aversion from intertemporal substitution and the non-additive intertemporal preference relations. This feature is not usually shared by the EU specification. However, the GEU form nests the EU form as a special case. The recursive CES EU (CES-EU) preferences, widely used in finance, macroeconomics and intertemporal consumption analysis, are obtained when we impose the parametric restriction  $\alpha = \rho$ .

$$(2.2) \quad \text{Max } U_t = \left\{ (1 - \beta) C_t^\alpha + \beta \left[ E_t \left( \tilde{U}_{t+1}^\alpha \right) \right] \right\}^{\frac{1}{\alpha}} \quad (\text{CES-EU})$$

Moreover, the standard multi-period recursive EU (MR-EU) preference is obtained when we further impose  $\alpha = \rho = 1$ . As indicated in equation (3), when the utility function is defined as a linear combination of current and future consumption levels, the optimization of MR-EU becomes a decision maker maximizing the summarized discounted expected consumption over a lifetime (finite or infinite time periods).

$$(2.3) \quad \text{Max } U_t = (1 - \beta) \left[ C_t + \sum_i \beta^i E_t \left( \tilde{C}_{t+i} \right) \right] \quad (\text{MR-EU})$$

Here  $C_{t+i}$  denotes consumption for the  $i^{\text{th}}$  period in the future. With risk preference  $\alpha = 1$ , the decision maker is risk neutral. The additive specification due to  $\rho = 1$  implicitly assumes preferences are homogeneous (perfectly substitutable) over time; each one of them carries the same weight when discounted to the current period. Such additivity is now well known to be too restrictive (Weil, 1990). Decision makers may have a clear preference for early resolution of risk compared to late resolution of risk (Kreps and Porteus, 1978).

### ***Application of GEU to Farmers' Intertemporal Decisions in the PNW***

When applying the GEU framework to our optimization problem, current consumption is further defined as net income from the farmer's wheat production and risk management. The farmer uses futures contract, yield insurance, and government programs to construct risk management portfolios. Hedge ratios and insurance coverage ratios are endogenous choice variables to be determined at the optimum, based on information available at  $t-1$ :

$$(2.4) \quad C_t = NC_t + CI_t + FI_t + GI_t$$

$$\text{where } NC_t = P_t Y_t - PC_t,$$

$$FI_t = \mathbf{x}_{t-1} [F_t - E_{t-1}(F_t)] - TC_t,$$

$$CI_t = P_b \max[0, \mathbf{z}_{t-1} E_{t-1}(Y_t) - Y_t] - Pre_t$$

$$GI_t = DP_t + LDP_t + CCP_t$$

$$\text{Where } DP_t = 0.85P_D \times 0.9E_{t-1}(Y_t),$$

$$LDP_t = E_{t-1}(Y_t) \max(0, L_R - P_t),$$

$$CCP_t = 0.85 \times 0.935 E_{t-1}(Y_t) \max[0, P_T - P_D - \max(P_t, L_R)]$$

where  $NC_t$  is the net income from producing and selling the crops in the cash market;  $CI_t$  is the net income from purchasing yield-based Multiple Peril Crop Insurance (MPCI);  $FI_t$  is the net income from hedging in the futures market; and  $GI_t$  is the net income from government programs.

$P_t$  and  $Y_t$  represent cash prices<sup>2</sup> and yields for winter wheat at harvest time respectively, with  $PC_t$  as the production cost.  $F_t$  is the futures price at time  $t$  and the futures market is treated as unbiased.  $\mathbf{x}_{t-1}$  is the hedging amount determined at a previous time period which is positive for a long position and negative for a short position.  $\mathbf{x}_{t-1}$  is in bold face to indicate its status as a choice variable.  $TC_t$  is the transaction cost of trading futures.  $P_b$  is the base price used to calculate the indemnity from crop insurance with  $Pre_t$  as the premium<sup>3</sup>.  $\mathbf{z}_{t-1}$  is the coverage selection of the insurance and is also in bold face to indicate a choice variable.  $DP$  is the direct payment program which gives a constant payment to farmers,  $LDP$  is the loan deficiency payment, and  $CCP$  is the counter cyclical payment.  $P_D$  is the direct payment rate,  $L_R$  is the loan rate, and  $P_T$  is the target price. The formulation of DP, LDP, and CCP is specified according to the 2002 Farm Bill and calibrated to PNW wheat growers, the chosen area for the empirical analysis.

Due to the nonlinearity in the objective function and the random interrelationships among variables, closed-form optimal solutions are unavailable in the dynamic optimization.

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<sup>2</sup> Cash price is a farm gate price after transportation cost is deducted from the spot market cash price.

<sup>3</sup> The premium of the current year's crop insurance is paid at harvest time.

Therefore empirical solutions are obtained by numerical methods. For the dynamic optimization, we simulate yields and prices for the next five years. Optimal levels of crop insurance coverage and hedge ratios are determined simultaneously and intertemporally in the presence of government programs.

#### **IV. Data, Simulation and Model Calibration**

##### ***Data Source***

We select a representative farmer from each of the two counties in Washington State, Whitman County and Grant County. Although both represent dryland soft white wheat farming region in the Pacific Northwest (PNW), these two counties have different levels of precipitation. Whitman County sits on the east central border of Washington and is part of the highest yield area for soft white wheat in the state. Whitman County has an average annual precipitation of around 14 inches. In comparison, Grant County is located in the center of the state and does not border Whitman County. Grant County is much dryer with an average annual rainfall of 5 inches in 2002. Accordingly, wheat production is riskier in Grant County. However, since there is some irrigation in Grant County, the yield is not much lower than that in Whitman County (Figure 2.1).

Historical data for soft white wheat yield, cash price and futures price for Whitman County and Grant County are collected and examined to identify time series patterns for simulation. The yield data for Whitman County and Grant County in Washington State are obtained from the U.S. Department of Agricultural National Agricultural Statistics Service (<http://www.usda.gov/nass/>) and Risk Management Agency (RMA) at annual basis for 1939-2003 and 1972-2003, respectively.

Annual September wheat cash and futures prices from 1973 to 2003 are selected to represent harvest prices. September is also the time when the farmer makes decisions on the following year's hedging and insurance participation, and prepares for the planting of next year's winter wheat crop. For cash price, we use the monthly average of daily September prices at the Portland spot market. The data are from the USDA-ERS Wheat Yearbook (<http://www.ers.usda.gov/publications/so/view.asp?f=field/whs-bb/>). Since the PNW region grows soft white wheat which has no actively traded futures contract, the Chicago Board of Trade (CBOT) September wheat futures contract is chosen by the farmer for hedging. We pick the mid-week price of the first week (Wednesday or Thursday) of September to develop our dataset.

### ***Deterministic Trend vs. Stochastic Trend***

Because of the multiple time dimensions involved in GEU specification and dynamic programming, simulation of yield data could affect the final optimization results to a large extent. Specifying a pattern that is consistent with real processes is critical in this study.

From the time series plots of Whitman County and Grant County yield (Figure 2.1) for 1972 to 2003, an upward trend is visible for the last 32 years. There are possibly two sources of randomness that influence the county yield time series. One is the stochastic technology changes that will determine the "mean" yield in any given year, and the other is the random weather that moves the yield around the "mean". For multi-period analysis, we need to model the long-run inter-year randomness from technology changes as well as the short-run random effects brought by weather. A stochastic trend model would be more appropriate than any deterministic trend models in that it incorporates both types of randomness.

Moss and Shonkwiler (1993) developed a single time-dependent stochastic trend model. Their model transforms the error term rather than the dependent variable to incorporate the possibility of both non-stationary data and non-normal errors in corn yield variation. The model is also general enough to include both the standard deterministic time trend and normal errors as special cases. This model is adopted for our analysis.

Similarly for wheat cash and futures prices (Figure 2.2), the long-run unpredictable balance of supply and demand determines the annual price trend, and short-run information at the market and other factors add more price variability around the trend. Therefore, this stochastic trend model is also fitted to price data.

The model consists of one measurement equation and two transition equations:

$$(2.5) \quad \begin{aligned} y_t &= \mu_t + \varepsilon_t \\ \mu_t &= \mu_{t-1} + \beta_{t-1} + \eta_t \\ \beta_t &= \beta_{t-1} + \zeta_t \end{aligned}$$

where  $y_t$  is the independent variable indexed by time  $t$ ;  $\begin{pmatrix} \mu_t \\ \beta_t \end{pmatrix}$  is the state vector;  $\varepsilon_t$  is the random error describing the short run randomness with mean zero and variance  $\sigma_\varepsilon^2$ ,<sup>4</sup>

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<sup>4</sup> The model also allows for a non-normal errors when  $\varepsilon_t$  is assumed to be generated by an inverse hyperbolic sine transformation from normality:  $e_t = (\tau_t - \delta) \sim N(0,1)$ , and

$\tau_t = \theta^{-1} \ln \left( \theta \varepsilon_t + \left\{ (\theta \varepsilon_t)^2 + 1 \right\}^{\frac{1}{2}} \right)$  where  $\delta$  is the non-centrality parameter;  $\delta > 0 (< 0)$  denotes the

distribution is skewed to the right (left) and if  $\delta = 0$  the distribution is symmetric.  $\theta$  is associated with the degree of kurtosis with  $\theta \neq 0$  denoting a kurtotic distribution. Thus, the error term can be expressed

as  $\varepsilon_t = \frac{e^{\theta \tau_t} - e^{-\theta \tau_t}}{2\theta}$ .



and  $\begin{pmatrix} \eta_t \\ \zeta_t \end{pmatrix} \sim N\left(\begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_\eta^2 & 0 \\ 0 & \sigma_\zeta^2 \end{pmatrix}\right)$  is the error vector describing the long run randomness in the transition equation that governs the evolution of the state vector. Both of the errors in the measurement equation follow normal distributions and are independent of each other.

In the basic specification,  $\mu_t$ , the mean component of the dependent variable, is shown as a random walk with a drift. Therefore the final generalization shows that the mean of the dependent variable grows at a random rate.

The stochastic trend model reduces to a deterministic time trend model if  $\beta_0 \neq 0$  and  $\sigma_\eta^2 = \sigma_\zeta^2 = 0$ . If  $\beta_0 = 0$ , then it reduces to a constant mean regression model.

### ***Estimation and Simulation for Yields and Prices***

Applying the stochastic trend model to our yield and price data using maximum likelihood estimation programmed in GAUSS, we find there is no stochastic trend in the yield for Whitman County but there is one for Grant County. The stochastic trend also exists in the Portland cash prices and CBOT futures prices (Table 2.1).

For Grant County yield, cash price and futures price, the significance of estimated  $\sigma_\eta$  confirms the existence of a random walk in the mean component. However, the insignificance of estimated  $\sigma_\zeta$  shows such stochastic variation doesn't exist within the mean of the trend. For Whitman County yield, however, the trend is generally a deterministic time trend and there is no significant randomness in the slope of the time trend. The simple linear regression model with a deterministic time trend appears to be a good model for Whitman County yield<sup>5</sup>.

The plots of predicted values versus actual values show that in general the stochastic trend models fit the data well by capturing the long-run variation in the trend for wheat yield in

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<sup>5</sup> We further test for autocorrelation within the series before applying the time trend and find no evidence.

Grant County (Figure 2.3) and cash prices (Figure 2.4)<sup>6</sup>. The 95 percent confidence intervals include nearly all of the realizations.

For the distributions of yield and prices, we conduct normality tests first on the detrended data. Results fail to reject the null hypothesis of normality. We also estimate the stochastic trend model including non-normal errors. The estimates of the non-normal parameters are not statistically different from zero, confirming that the data follow a normal distribution.

We use the fitted linear time trend model to simulate annual wheat yields in Whitman County for the next five years, and use the fitted stochastic trend models to simulate Grant County yield, Portland Cash price, and CBOT futures price. An empirical distribution with 2000 samples is simulated for each of the next five years and for each series. All the series are first simulated independently without autocorrelations or contemporaneous correlations. For the cash and futures prices, we then impose a correlation of 0.871 based on historical data. Table 2.2 gives the descriptive statistics of the simulated data.

### ***Parameter Calibration***

Identification of farmers' risk preferences and time preferences has been attempted in previous studies using different models (Saha, Shumway and Talpaz, 1994; Chavaz and Holt, 1996; Epstein and Zin, 1990; Lence, 2000). Among them, Lence used a similar dynamic GEU model to estimate US farmers' preference parameters based on aggregated consumption and asset return data from 1966-1994. We implement those estimates,  $\alpha = -0.13$ ,  $\beta = 0.89$  and  $\rho = 0.9493$ , as the base for our representative farmers and assume they stay fixed over time.

In the determination of current consumption (or net income) level, transportation cost between the Portland spot market and the two counties is set at \$0.50 per bushel for Whitman

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<sup>6</sup> Similar pattern is also shown for wheat futures prices.

County and \$0.47 for Grant County; production cost is determined as \$203 per acre for Whitman County (Hinman and Baldree, 2004) and \$195 for Grant County<sup>7</sup>; transaction cost associated with hedging is set at \$0.017/bushel. The price used to indemnify crop loss in the insurance programs is the CBOT September wheat futures price plus a Portland basis of \$0.45 per bushel. The insurance coverage levels are restricted to be either zero or from 50% to 85% with an increment of 5%. The insurance premium is computed as the product of the expected indemnity (actuarially fair premium level) and 1 minus the regressive subsidy rate specified in current policies<sup>8</sup>.

For government programs, the direct payment rate  $P_D$  is set at \$0.52 per bushel. The base yield used to calculate a per acre payment is set at 90 percent of the expected yield. The loan rate ( $L_R$ ) for the *LDP* is \$2.86 per bushel for soft white wheat in Whitman County and \$2.91 per bushel in Grant County. The target price ( $P_T$ ) for CCP is \$3.92 per bushel. These parameters are based on current US farm policies.

## V. Results

We implement the stochastic dynamic optimization programming using GAUSS and numerically solve for the optimal hedge ratios and crop insurance coverage ratios for our representative farmers in the two Washington State counties (Whitman and Grant). Results are shown in Table 2.3. Note that all the hedge ratios are reported without the negative sign, which indicates hedging is in short position in all cases.

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<sup>7</sup> Production cost for Grant County is derived based on budgeting report for Lincoln County, a similarly dry county in Washington State. Reference: Esser, Hinman, and Platt (2003).

<sup>8</sup> The subsidy rate corresponding to the coverage levels of 50, 55, 60, 65, 70, 75, 80, and 85 percent are respectively, 67, 64, 64, 59, 59, 55, 48, and 38 percent.

As we can see, the specification of the GEU model gives us extra flexibility in the parameterization of the objective function. We are able to explore the feasibility of the GEU model as well as to compare the results from GEU optimization with those from other widely used expected utility optimization models. The base scenario ( $\alpha = -0.13$ ,  $\beta = 0.89$  and  $\rho = 0.9493$ ) represents the farmer who is risk averse ( $\alpha < 1$ ) and prefers an early resolution of the risk to a late resolution ( $\alpha < \rho$ ). The farmer discounts future consumption by a factor of 89% and makes a decision for the next five years based on all available information as of today.

Other scenarios of interest in our study include the two special cases of the GEU base model, CES-EU optimization with  $\alpha = \rho = -1$  and  $\beta = 0.89$ , and MR-EU optimization with  $\alpha = \rho = 1$  and  $\beta = 0.89$ . The former refers to the case where the farmer is more risk averse and has smaller intertemporal substitution preference in consumption, while the latter refers to the case when he/she is risk neutral and has perfect intertemporal substitution preference.

Besides the CES-EU and MR-EU, a multi-period additive EU (MA-EU) optimization is also examined. The utility function in this case is the standard constant relative risk aversion utility function  $U_t = \frac{C_t^\alpha}{\alpha}$  where  $\alpha = -1$ , which implies a relative risk aversion coefficient equal to 2. This utility function has been widely used in static single-period risk analyses (Mahul, 2003; Wang, Hanson, and Black, 2003; Coble, Heifner, and Zuniga, 2000). It is also easy to extend the model from single-period to multi-period as in equation (2.6), but note that this multi-period version has a static nature.

$$(2.6) \quad \text{Max} U_t = \left[ \sum_i \beta^i E_t \left( \frac{\tilde{C}_{t+i}^\alpha}{\alpha} \right) \right] \quad (\text{MA-EU})$$

Table 2.3 lists results of the Whitman County farmer's optimal choice on risk management portfolios using the four different models. In general, we see that model specification is very important in modeling farmer's risk management behavior and finding the optimal portfolios for farmers' intertemporal decision.

For the optimal choice of crop insurance, the highest coverage of 85% is favored in all cases. This result is consistent with the model setting since the insurance is subsidized by the government and no premium loading is charged. The farmer purchases the highest available level so as to enjoy the most protection against yield risk and receive the highest subsidy. Also, the government commodity programs provide free price protection with a sizable expected income transfer. The farmer will always participate, which reduces the need for futures hedging.

From the hedge ratios, we can see the hedging levels are always below 32%. This is because first there is a transaction cost in hedging. Second, the government LDP and CCP programs also have price risk reduction features, which leads to a crowding out effect on hedging. Similar results are reported in Wang, Makus, and Chen (2004). The pattern of the hedging ratio is different in the GEU base model relative to the other models, and the level of hedging is slightly higher in the GEU full optimization. With risk aversion, time preference, and intertemporal substitution separately specified, the GEU full model shows the farmer's optimal hedge ratios is increasing over the first four years. The generally higher level of hedging, compared with results from other alternative models, implies he/she prefers to resolve the risk earlier rather than later. Although the farmer prefers an early resolution of risk, his or her relatively high intertemporal substitutability of consumption may balance the preference in a way that hedging would be kept at a slightly increasing rate to meet the increasing price volatility. In the fifth and final year, the farmer would reduce spending on hedging and accept more risk.

In the CES-EU model, the farmer's risk aversion and intertemporal substitution of consumption is integrated as one preference. The optimal hedge ratio is higher in the first year and then becomes lower in the second through the fifth years compared to the corresponding ratios in the GEU full model. The CES-EU model also displays a decreasing pattern over the five years. The higher level of hedging in the first year is consistent with the farmer's higher risk aversion. The pattern switches for the second year, however. Since the risk aversion and substitution preference are mixed together in this case, the effects of the two preferences are hard to differentiate in a cross-year setting. They may be competing against or reconciling with each other, which, neither of which is observable.

The CES-EU results are comparable to the MA-EU results in that they both share the same risk aversion. Interestingly, these two models yield nearly the same optimal hedge ratios. We have further checked with other risk aversion values including  $\alpha = -2$  and  $\alpha = 0.5$ , and get similar results. The comparison gives the impression that these two models work very similarly in modeling the optimization behavior for the decision maker's risk management. This result indicates that although the GEU does not include the popular additive EU models for risk averters, its CES-EU component is equivalent. So, GEU is perhaps more general than it appears.

As a very special case of the GEU model, the MR-EU model applies to a farmer who is risk neutral and has perfect intertemporal substitutability in consumption. Consistent with these preferences, the optimal hedging ratio is zero for each year, reinforcing that the decision maker does not care about risks and has no specific concerns regarding consumption across years.

Optimal choices for the representative farmer in Grant County are very similar to Whitman County. The farmer prefers slightly less hedging than the Whitman farmer but still buys the same coverage of crop insurance. Although the production is riskier in Grant County

because yield is a bit more stochastic, there is no huge gap between the yield levels as shown in the historical data (Figure 2.1). Also we assume farmers in both counties face the same prices, so they are exposed to the same price risks. The hedge ratios are very close to those in Whitman County under the same preference set.

In summary, the comparisons between the four models for Whitman County and Grant County in Washington State show that the GEU model is feasible by yielding reasonable results on optimal risk management portfolios. For a farm planning on multi-period management, GEU shows an optimal strategy that is more consistent with reality on hedging and crop insurance for the decision maker, who wants to maximize utility over the whole time span. The GEU model framework is also flexible enough to account for separate risk, time, and substitution preferences, and is able to incorporate other commonly used EU models that have either ignored intertemporal substitution preference or integrated such substitution with risk preference.

## **VI. Summary and Conclusions**

In this study we extend the GEU maximization framework to analyze a risk management problem related to wheat production in the PNW. A representative soft white wheat grower in Whitman County and Grant County, Washington, maximizes his or her utility by selecting an optimal portfolio of risk management tools including hedging in the futures market, purchasing crop insurance, and participating in government commodity programs. The GEU model allows the decision maker to completely specify risk preference, time preference, and intertemporal substitution preference. It also incorporates other common expected utility maximization models like CES-EU and MR-EU models as special cases. A very popular but different type of static EU (MA-EU) model is also added for comparison purpose.

We solve the maximization problem numerically based on simulated yield and price data for the next five years. In simulating the data, we apply a stochastic trend model which is able to capture stochastic properties within the long-run trend in addition to those from the short-run disturbances. It is also general enough to include the deterministic time trend model as a special case. Stochastic trends are found in the historical Grant County yield, Portland cash price, and CBOT futures price.

We find optimal solutions for farmers in both Whitman County and Grant County vary with model specifications, indicating the importance of appropriate model selection and parameterization. The GEU model is feasible in modeling farmers' risk management decisions in both counties by giving more reasonable results and the general form of GEU has advantages in incorporating more preference information about the decision maker. The commonly used MA-EU model gives almost the same results when the risk aversion is specified at the same level as in the CES-EU, indicating that these two types of models might be interchangeable. However, these results are different than the GEU model when the preferences parameters are set at different levels. This shows that (1) GEU is more general and can incorporate more flexible preference, (2) the commonly used additive EU models may yield biased results relative to the decisions based on the true preference. The results are completely different in the risk neutral and perfect substitution MR-GEU setting.

The optimal choice of the hedging ratios is around 30% and that of the crop insurance purchase is always 85% in both counties. These levels are in line with the existing static one period studies. The subsidy in crop insurance overshadows its risk management feature so that the optimal insurance coverage is invariant with respect to the preference alternatives.



Although we have obtained favorable results concerning the feasibility and flexibility of the GEU model, further research on the GEU framework and its applicability in modeling and explaining dynamic agricultural risk management issues is still important and necessary. First, sensitivity analyses of the optimal solutions in response to the preference changes and to changes in risk management tools may provide information on farmers' preference dynamics and policy impact issues. Such sensitivity analyses will help further explore the advantages of the GEU optimization model. Second, our results so far only focus on the two counties which are geographically close to each other. It will be interesting to extend the research to other locations where there is more heterogeneity in farmers' price and yield risks. Third, other instruments such as revenue insurance products should be investigated to make additional contributions in policy analysis.

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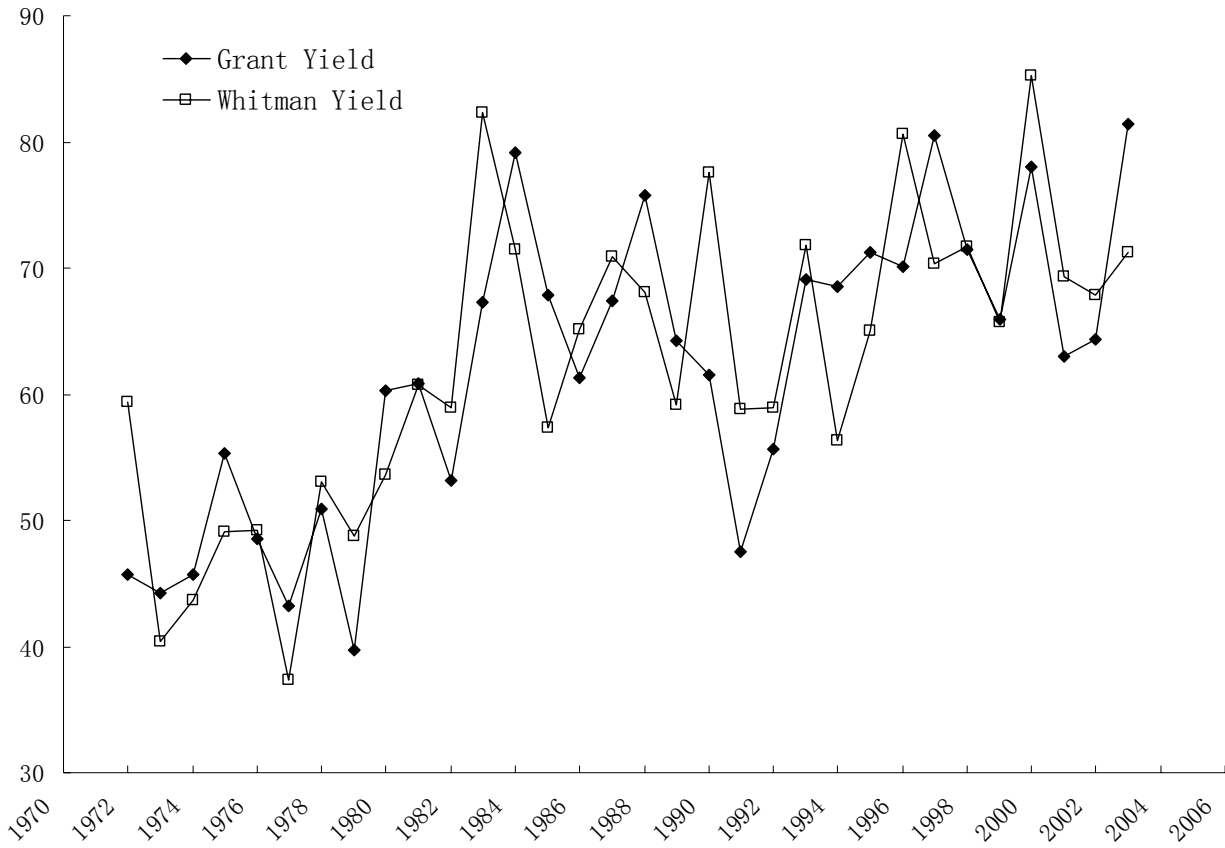
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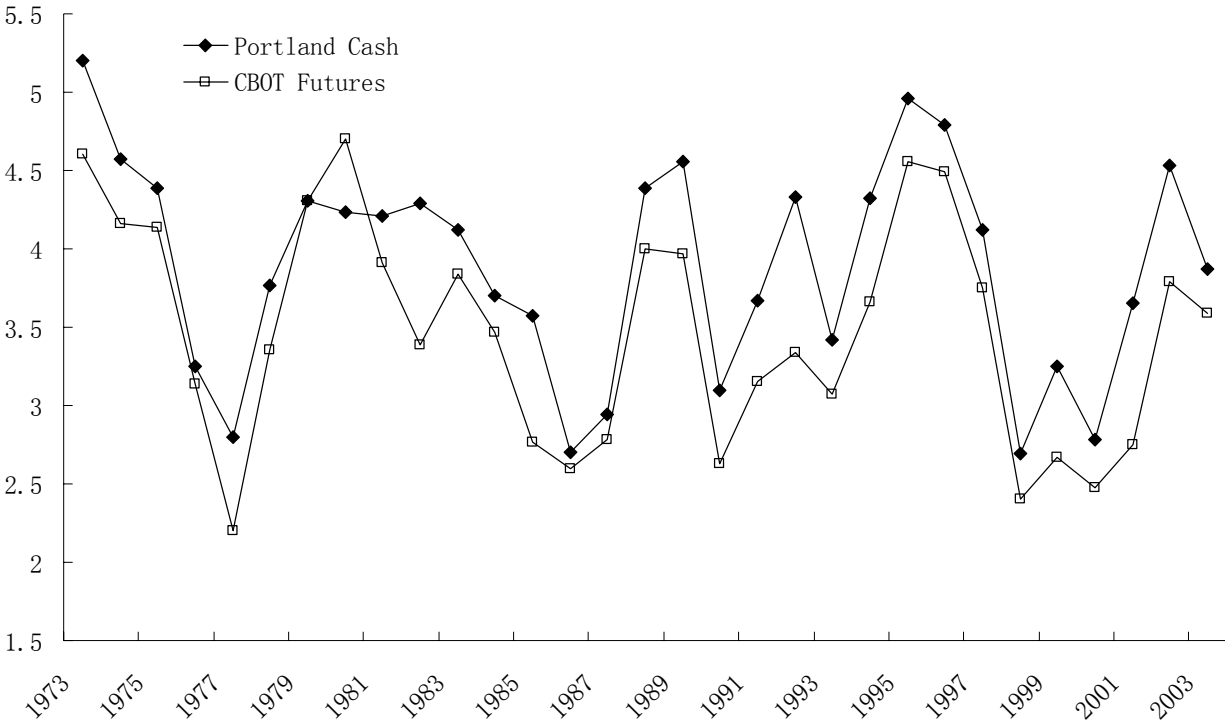
**Figure 2.1. Historical Soft White Wheat Yields in Whitman and Grant (1972-2003)**

Unit: Bushel/Acre



**Figure 2.2. Historical Wheat Cash and Futures Prices (1973-2003)**

Unit: Dollar/Bushel



**Figure 2.3. Stochastic Trend Model Fitting for Grant Wheat Yield (1972-2003)**

**Predicted vs. Actual**

Unit: Bushel/Acre



Note: The lower bound and upper bound are based on 95% confidence intervals.



**Figure 2.4. Stochastic Trend Model Fitting for Wheat Cash Prices (1973 to 2003)**

**Predicted vs. Actual**



**Table 2.1. Stochastic Trend Estimation of Historical Yield and Price Data**  
(Normal distribution)

Parameter	Whitman Yield	Grant Yield	Cash Price	Futures Price
$\mu_0$	27.29** (3.63)	44.22** (6.29)	5.24** (3.25)	4.64 (3.24)
$\beta_0$	0.73 (1.00)	0.94 (1.16)	-0.04 (1.02)	-0.03 (1.11)
$\sigma_\varepsilon$	7.13** (0.63)	6.92** (1.46)	0.00 (1.02)	0.00 (0.23)
$\sigma_\eta$	0.00 (0.15)	3.10* (2.04)	0.75* (0.10)	0.71* (0.09)
$\sigma_\zeta$	0.00 (0.03)	0.00 (0.25)	0.00 (0.07)	0.00 (0.07)

Note: 1. Standard errors of the estimates are included in the parentheses.

2. “\*” denotes the estimate is statistically significant at 0.10 level, and “\*\*” denotes significance at 0.05 level.

**Table 2.2. Descriptive Statistics of the Simulated Yield and Price Data**

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Statistics	Year1	Year2	Year3	Year4	Year5	Year1	Year2	Year3	Year4	Year5
	<i>Whitman Simulated Yield (bushel/acre)</i>					<i>Grant Simulated Yield (bushel/acre)</i>				
Mean	75.28	75.93	76.77	77.36	78.24	75.19	76.27	76.30	77.34	78.02
Std Dev.	7.26	7.22	7.28	7.06	7.23	7.49	8.15	8.36	9.46	9.65
Skewness	-0.01	-0.03	0.02	0.07	-0.04	-0.08	-0.02	0.03	-0.05	0.02
Kurtosis	0.24	0.14	-0.03	0.07	-0.005	0.08	0.26	-0.09	0.16	-0.4
	<i>Portland Cash Price (dollar/bushel)</i>					<i>CBOT Futures Price (dollar/bushel)</i>				
Mean	3.93	3.86	3.82	3.79	3.77	3.56	3.51	3.49	3.46	3.44
Std Dev.	0.66	0.91	1.07	1.21	1.34	0.68	0.96	1.15	1.29	1.44
Skewness	0.02	0.02	0.06	0.10	0.06	-0.04	0.02	0.10	0.07	0.05
Kurtosis	-0.05	0.06	-0.06	0.20	-0.12	0.03	0.01	-0.20	-0.26	-0.31

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**Table 2.3. Optimal Hedge Ratio and Crop Insurance Coverage: Model Comparison**

Alternative Model  Specifications	Hedge Ratio					Crop Ins. Cov. Ratio
	Year1	Year2	Year3	Year4	Year5	Year1-5
<b><i>Whitman County</i></b>						
GEU full ( $\alpha = -0.13, \beta = 0.89, \rho = 0.9493$ )	0.25	0.31	0.32	0.32	0.26	0.85
CES-EU ( $\alpha = \rho = -1, \beta = 0.89$ )	0.29	0.27	0.25	0.25	0.22	0.85
MR-EU ( $\alpha = \rho = 1, \beta = 0.89$ )	0	0	0	0	0	0.85
MA-EU ( $\alpha = -1, U(C) = -1/C, \beta = 0.89$ )	0.29	0.27	0.25	0.25	0.22	0.85
<b><i>Grant County</i></b>						
GEU full ( $\alpha = -0.13, \beta = 0.89, \rho = 0.9493$ )	0.25	0.31	0.32	0.32	0.24	0.85
CES-EU ( $\alpha = \rho = -1, \beta = 0.89$ )	0.31	0.28	0.26	0.25	0.21	0.85
MR-EU ( $\alpha = \rho = 1, \beta = 0.89$ )	0	0	0	0	0	0.85
MA-EU ( $\alpha = -1, U(C) = -1/C, \beta = 0.89$ )	0.31	0.28	0.26	0.25	0.21	0.85

## CHAPTER 3

# THE IMPACTS OF INTERTEMPORAL PREFERENCES, MARKET INSTITUTIONS, AND GOVERNMENT POLICIES ON FARMERS' RISK MANAGEMENT BEHAVIOR AND WELFARE

**Abstract:** This paper applies the generalized expected utility (GEU) approach developed by Epstein and Zin (1989, 1991) to dynamic agricultural risk analysis. We explore the impacts of alternative preference parameters of farmers including risk aversion, time preference, and intertemporal substitutability on their optimal risk management portfolio selection. The portfolio includes hedging in the futures market and participating in crop insurance and government commodity programs. Furthermore, we introduce a welfare measure into the GEU model, the certainty equivalent, and investigate farmers' welfare improvement provided by U.S. government programs and market institutions. We find farmers' optimal hedge ratio is sensitive to changes in preferences, and the effects of these preferences changes are intertwined. The market institution impact analysis shows that transaction cost of hedging negatively affect optimal hedge ratios and reduce farmers' welfare. Target price and loan rate level, which impact the loan deficiency payment and counter-cyclical payment programs, play an important role in hedging decisions and lead to substitution effects for hedging. The policy impact analysis shows both crop insurance and government payments are influential to farmers' welfare improvement. Government payment programs have a greater effect on farmers' welfare than crop insurance and crop insurance outperforms hedging.

**Keywords:** intertemporal preferences, market institution, policy, GEU, risk management

## **I. Introduction**

Farmers' intertemporal consumption preferences are heterogeneous in that they have different risk attitudes, different time values, and different substitution preferences. The risk management resources in the US also changes over time as new policies and market institutions are constantly developed to improve risk protection for farmers. The most commonly used risk management instruments are futures contracts, crop insurance programs, and government commodity payment programs. These programs are revisited and adjusted every few years. In order to effectively utilize these risk protection programs, farmers need to adjust their expectations as well as risk management strategies throughout the production process.

Farmers have traditionally used hedging in the commodity futures markets to seek price risk management. Hedging has a long history of being one of the most available and direct risk management tools for farmers. Since the 1980s, farmers' use of crop insurance products has increased largely as the Federal Crop Insurance Corporation expanded Multi-Peril Crop Insurance (MPCI), and later included other yield and revenue insurance products. Now crop insurance has become the most popular risk management tool for the U.S. crop producers.

In recent years, the federal government increased its involvement in providing and facilitating risk protection instruments to farmers. The 2002 Farm Bill includes three major programs to farmers: a loan deficiency payment (LDP), a direct payment (DP), and a counter cyclical payment (CCP). The LDP and DP are inherited from the 1996 bill, and the CCP is a new program added to the 2002 bill as a revision and resumption of the deficiency payment program in the 1990 bill. These payment programs work as price insurance but without any premium charge. However, the programs are usually offered for a multi-year period. Provisions require

that farmers make the decision on weather or not to participate in the programs at the beginning of the period.

Farmers' decision making and welfare are based on individual preferences in a given risk and policy environment. In a generalized expected utility (GEU) maximization model proposed by Epstein and Zin (1989) and Weil (1990), a class of recursive preferences was developed over intertemporal consumption sets. The constant elasticity of substitution (CES) form of the objective utility function allows risk aversion to be disentangled from intertemporal substitutability of consumption. Generally a decision maker's expected utility is subject to changes in three types of preferences: risk aversion, time discounting, and intertemporal substitutability. His or her intertemporal decisions are determined by the mutual effects of all these preferences. According to the model, uncertainty about consumption is resolved over time and preference orderings generally imply non-indifference to the way it resolves. An earlier (later) resolution of consumption is generally preferable when risk aversion is greater (less) than intertemporal substitutability. The GEU model provides a possibility to study farmers' intertemporal risk management decisions while considering their preferences toward risk, time, and inter-year substitution of consumption. It also allows us to examine the impacts of changing U.S. agricultural policies on farmers' behavior at the same time.

The objective of this paper is to investigate the impacts of intertemporal preferences towards risk, substitution, and time, as well as market institutions and policy alternatives, on farmers' risk management behavior in a dynamic GEU maximization setting. We are also interested in evaluating the different risk management tools and weighing their roles in risk management portfolios. The rest of the paper is organized as follows. Section II gives a general review of literature. Section III introduces the data source and method used for estimation,

simulation, and optimization. Section IV discusses the results and Section V summarizes the findings and draws conclusion.

## **II. Previous Research**

Analyses of decision maker's preferences have drawn attention in the literature and have been examined in many empirical economic studies (Hansen and Singleton, 1982, 1983; Hall, 1988). Most of the research has focused on identifying or estimating preferences rather than studying the role of the preferences in making optimal decisions. Within the agricultural economics literature, the focus has been on the estimation of risk and time preferences (Saha, Shumway, and Talpaz, 1994; Chavas and Holt, 1996; Barry, Robinson, and Nartea, 1996), or on risk management analyses under certain given preferences (Coble, Heifner, and Zuniga, 2000; Mahul, 2003).

Instead of focusing on instruments like hedging or crop insurance separately, many recent studies on risk management strategies have been extended to portfolio analysis and focus more on the interactions and relative impacts of the instruments within a portfolio. For example, there are portfolios of crop yield insurance and futures contracts (Myers, 1998), futures market and government farm programs (Crain and Lee, 1996), and crop yield insurance, futures, options and government programs (Wang, et al., 1998). Dhuyvetter and Kastens (1999) concluded that hedging reduces the risk management advantage of revenue insurance over yield insurance. Zuniga, Coble, and Heifner (2001) found that crop revenue insurance works better than yield insurance when no market instrument is used. Yield insurance, however, becomes competitive when market-based pricing instruments are included in the portfolio. Wang, Makus, and Chen (2004) detected some crowding-out effects of government programs on hedging.



Studies on measuring farmers' welfare change are found in literature, but very few concentrate on farmers' welfare changes under different risk management portfolios. Wang, et al (1998) found Iowa corn farmers' willingness to pay decreases as the trigger yield level of crop insurance increases at a decreasing rate. Mahul (2003) found futures and options would improve French wheat producers' willingness to receive when hedging is used in the presence of crop insurance. Wang, Makus and Chen (2004) found U.S. farm program payments account for the primary value of all risk management portfolios for Pacific Northwest dryland grain producers.

Most of the research discussed so far was based on a traditional expected utility (EU) maximization framework. When Epstein and Zin developed GEU, the decision maker's risk aversion was able to be disentangled from intertemporal substitutability. In their empirical paper, Epstein and Zin (1991) found the elasticity of substitution is typically small (always less than one). Additionally, risk preference defined as one minus constant relative risk aversion (CRRA) does not significantly differ from zero (CRRA close to one). As the only one who has used the GEU approach to study agricultural risk management, Lence (2000) estimated U.S. farmers' time preferences and risk attitudes based on historical data from 1936 to 1994. The estimates are consistent with theory. Farmers have time preference around 0.95, substitution parameter for consumption around 0.9, and CRRA greater or close to one. In particular, farmers have become less risk averse over time.

Other possible applications of GEU, like sensitivity analyses of dynamic optimization solutions with respect to a decision maker's preferences and other exogenous variables, have not been explored. No one has attempted developing a welfare measure in GEU models. Adaptation of this framework specifically to agricultural risk management portfolio studies has not been

available in the literature<sup>9</sup>. This chapter will make an effort to contribute to the literature from this perspective.

### III. Model

We use the base GEU model, model (1) developed in Chapter 2, for the impact analysis in this paper. This base model allows complete parameterization of preferences and allows a flexible structure of the risk management portfolio. Again, the model is specified as follows: a decision maker attempts to maximize his or her CES expected utility of consumption, under a set of preferences in risk, time, and intertemporal substitution of consumptions;

$$(3.1) \quad \underset{x}{\text{Max}} U_t = \{(1 - \beta)C_t^\rho + \beta[E_t(\tilde{U}_{t+1}^\alpha)^\frac{\rho}{\alpha}]\}^\frac{1}{\rho}$$

where the current consumption,  $C_t$ , is defined as a net income from production and risk management using crop insurance, futures hedging, and government programs;

$$(3.2) \quad C_t = NC_t + CI_t(z_{t-1}) + FI_t(x_{t-1}) + GI_t$$

where  $NC_t$  is the net income from producing and selling the crops in the cash market;  $CI_t$  is the net income from crop insurance;  $FI_t$  is the net income from hedging in the futures market; and  $GI_t$  is the net income from government programs. Hedge ratios  $x_{t-1}$  contained in  $FI_t$  and insurance coverage ratios  $z_{t-1}$  contained  $CI_t$  are endogenous choice variables to be determined at the optimum, based on information available at  $t-1$ .<sup>10</sup>

Government programs include three major payment programs; the direct payment ( $DP$ ), the loan deficiency payment ( $LDP$ ), and the counter-cyclical payment ( $CCP$ ). They are specified as:

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<sup>9</sup> Chapter 2 of this dissertation, however, has shown an application of the GEU model.

<sup>10</sup> Detailed specifications of each component can be found in the previous chapter.

$$(3.3) \quad \begin{aligned} DP_t &= 0.85P_D \times 0.9E_{t-1}(Y_t), \\ LDP_t &= E_{t-1}(Y_t) \max(0, L_R - P_t), \\ CCP_t &= 0.85 \times 0.935 E_{t-1}(Y_t) \max[0, P_T - P_D - \max(P_t, L_R)] \end{aligned}$$

where  $P_D$  is the direct payment rate,  $L_R$  is the loan rate, and  $P_T$  is the target price. The formulation of  $DP_t$ ,  $LDP_t$ , and  $CCP_t$  is specified according to the 2002 Farm Bill and calibrated to the Pacific Northwest (PNW) wheat growers, the chosen area for the empirical analysis in this paper.

To further measure the risk management value and the income transfer value of alternative risk management instruments to the farmer, we extend the base GEU model by introducing a certainty equivalent (CE) variable. We choose CE to evaluate alternative risk management portfolios relative to cash sales, under certain specified preference sets. Here CE is the certain amount of money that would be offered to the farmer in every period to keep him or her as well off as providing the farmer with the specified risk management portfolio. CE can be calculated by solving:

$$(3.4) \quad U_t(C_t, E_t(C_{t+1}^*, C_{t+2}^*, \dots, C_{t+i}^*)) = U_t(C_t^0, E_t(C_{t+1}^0 + CE, C_{t+2}^0 + CE, \dots, C_{t+i}^0 + CE))$$

where  $C_{t+i}^*$ ,  $i = 1, 2, \dots$ , is the optimal consumption (net income) under a specific portfolio in the next  $i^{th}$  period, and  $C_{t+i}^0$ ,  $i = 1, 2, \dots$ , is the net income from selling in the cash market which is defined as the  $NC_t$  for that period.

#### **IV. Data, Simulation, and Model Calibration**

##### ***Data Source and Simulation***

The impact analyses in this paper are based on the risk management practices of a representative farmer from Whitman County in Washington State. Historical annual data for soft white wheat yield (1939-2003), cash prices and futures prices (1979-2003) are collected and

examined to identify time series patterns. After a stochastic trend model fitting, the yield and prices are simulated for the next five years based on the fitted models. A deterministic time trend model is used to simulate future yields, while a stochastic trend model is used to simulate future cash prices and futures prices.

The source and process of data collection, time series model fitting, and data simulation are discussed in detail in Chapter 2. Therefore, we directly import the simulated Whitman County data series to the base model in this chapter without adjustment or manipulation.

### ***Parameter Calibration***

Again, the full discussion of the parameter calibration is included in Chapter 2. Here we briefly repeat the results. In the base model, the preferences are set at  $\alpha = -0.13$ ,  $\beta = 0.89$  and  $\rho = 0.9493$  for the representative farmer, as estimated by Lence (2000) based on US farmers' consumption data from 1966 to 1994. For the impact analysis, we will allow the values to vary, one at a time, within the theoretical ranges, i.e.  $0 \neq \alpha < 1$ ,  $0 < \beta < 1$ , and  $0 \neq \rho < 1$ .

In the determination of a current consumption (or net income) level, transportation cost between the Portland spot market and Whitman County is set at \$0.50 per bushel; production cost is determined as \$203 per acre; and transaction cost associated with hedging is set at \$0.017/bushel. The price used to indemnify crop loss in the insurance programs is the CBOT September wheat futures price plus a Portland basis of \$0.45 per bushel. The insurance coverage levels are restricted to be either zero or from 50% to 85% with an increment of 5%. The insurance premium is computed as the product of the expected indemnity (actuarially fair premium level), and 1 minus the regressive subsidy rate specified by current policies.

For government programs, the direct payment rate  $P_D$  is set at \$0.52 per bushel. The base yield used to calculate a per acre payment is set at 90 percent of the expected yield. The loan rate ( $L_R$ ) for the *LDP* is \$2.86 per bushel for soft white wheat in Whitman County. The target price ( $P_T$ ) for CCP is \$3.92 per bushel. These parameters are based on current US farm policy provisions.

## V. Results

Based on GEU maximization, we examine the impacts of risk aversion, time preference, and intertemporal substitutability on farmers' optimal choice of hedging and crop insurance participation through parameterization of the preferences. By setting the price instruments with futures contracts, insurance policies, and government payments at different levels, we examine the impacts of market institutions. In addition, we investigate the relative impacts of each of the major risk management tools through various ways of constructing a risk management portfolio. These impacts are not only reflected in the optimal level of hedge ratios, but also in the cash value associated with the choice.

In order to differentiate the impacts of intertemporal preferences from those of market and policy alternatives, we consider three cases. First, assume the set of policy and market risk management tools stays the same while farmer's preferences vary, with the preferences changing one at a time. Second, only allow crop insurance to change parameters while keep hedging and government program parameters invariant. Last, we change government programs parameters and leave futures and crop insurance unchanged.

### *Impacts of Preferences: Risk Aversion, Time Preference, and Intertemporal Substitutability*

We solve the GEU optimization problem by dynamic programming using GAUSS for risk aversion parameter ranging from -5 to 1 (Arrow-Pratt CRRA coefficient from 0 to 6), time discount factor from 0.1 to 0.9, and substitution preference from -5 to 1. The examinations are conducted separately for each of the preferences. We change only one preference parameter at a time, while holding the other two preferences at the same level as in the base scenario.

Theoretical restrictions on the parameters have been considered so that only feasible values were assigned within each range.

At this time, the farmer can choose from hedging in the commodity futures market and a no-load MPCY yield insurance. He or she is also able to receive government payments through DP, LDP, and CCP. The parameterization for these risk management instruments is at the base level. Results show that differences in the optimal portfolio are only in hedge ratios, the crop insurance purchase ratios are always at 85% level. Therefore, we focus on the variation in hedge ratios in the following discussion.

#### *Risk Aversion*

Figure 3.1 displays how hedge ratios in the next five years respond to risk aversion ( $\alpha$ ) changes<sup>11</sup>. In general, the farmer's optimal hedge ratios<sup>12</sup> are sensitive to variations in  $\alpha$ . In the first year, which is the most responsive, a 1% increase in  $\alpha$  (from around -3 to close to 1) results in a 0.74% decrease in the hedge ratio (from 35% to close to 0). Regarding the evolution of hedge ratios for each year, it shows a similar pattern throughout the five years. All ratios first increase very slowly when the farmer's risk aversion varies at higher levels ( $\alpha$  from -3 to -1 or

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<sup>11</sup> We only select some "typical" values of risk aversion to display in the graph for space consideration. We did the same in the graphs of time preference and intertemporal substitutability. Complete results are in Appendix A.1-A.3.

<sup>12</sup> Here all hedge ratios are in short positions. When referring to hedge ratios, we usually mean the magnitude rather than the sign unless specifically stated.

CRRA from 4 to 2). Then the ratios switch one by one to decrease as risk aversion gets smaller. Specifically, the turning points are at  $\alpha$  equal to -3, -0.8, -0.6, 0.1, and 0.6 for the first until fifth year, respectively. After the turning point, hedge ratios generally decrease at a faster rate. This decreasing pattern seems more consistent with the intuition that less risk averse people would tend to hedge less. However, the increasing pattern before the turning point is still possible to happen. Similar patterns have been seen in empirical dynamic hedging research (Martinez and Zering, 1992).

At a specific risk aversion level, the optimal hedging level appears to decrease over the five years if the farmer is highly risk averse ( $\alpha$  less than -2). The pattern is almost reversed if the farmer is not very risk averse ( $\alpha$  greater than 0.2). For farmers who have mild risk aversion, the pattern is mixed. Depending on the specific point he or she is at, the farmer may hedge more either in the early stages or in the later stages. Theoretically,  $\alpha < (>)\rho$  indicates the decision maker prefers early (late) resolution. Therefore when the farmer is very risk averse, he or she would want to resolve risk as early as possible by hedging more in early years, and vice versa. However, hedging reduces risks but also costs the farmers some certain income because of the futures transaction cost. As  $\alpha$  and  $\rho$  get close, although  $\alpha < \rho$  holds for the entire range in Figure 3.1, the preference of early resolution gets weak and the time discount of fixed transaction cost makes the farmer want to hedge less earlier and more later. Similar observations also exist in the sensitivities of time preference and intertemporal substitution.

### *Time Preference*

From Figure 3.2 we notice that the hedge ratios are responsive to time preference changes but not as much as to risk aversion. The most responsive ratio is for the first year, but it only varies between 32% and 25%. Ratios for the second to fourth year only change from 30% to

32%, and ratio for the fifth year has only minor changes. Second, hedge ratios have a convex pattern but only the turning points for the first two years ( $\beta = 0.3$  and  $0.5$ , respectively) are observable within the range of  $\beta$ . Third, for the last year when farming is about to end, the hedge ratio is always around 25.5% for all  $\beta$  levels, quite different from the other years, especially those for the second to fourth year.

Since  $\beta$  is defined as the time discount factor, by postponing consumption to next period the farmer only gets a fraction ( $\beta$ ) of the utility that he or she would get by consuming an equal amount during the current period. Therefore with a higher  $\beta$ , the farmer will have a greater propensity to consume in the future instead of the current time period. In our case, as  $\beta$  becomes bigger or the future consumption is less discounted, the farmer values the future income and income risk more than today's, and hedging decreases in the early years. The hedge ratios are increasing during the third until fifth year over all  $\beta$  values, and increasing for the first two years before  $\beta$  gets to the turning point.

At a specific time preference level, the farmer tends to hedge more in earlier years due to a preference for an early resolution of consumption risk. This pattern is more obvious in hedge ratios when  $\beta$  is low, but it then slowly changes as hedge ratios move to the turning point.

#### *Intertemporal Substitutability*

Optimal hedge ratios are generally sensitive to changes in intertemporal substitutability as shown in figure 3.3. Hedging percentages are primarily increasing as  $\rho$  gets larger. The pattern switches when  $\rho$  reaches the turning point in the first and second year.

A larger  $\rho$  represents a more substitution of consumption across years. Therefore, optimal hedge ratios differ for large versus small  $\rho$  values across the first four years, most



noticeably in the third and fourth year. For a range between -5 to 0.8, the increase in  $\rho$  for a given  $\alpha$  ( $\alpha = -0.13$ ) also affects attitudes towards risk and timing. The farmer's preference toward resolution of risk will change from late to early. Combined with the increasing substitution effect of late consumption for early consumption, it can be seen that hedge ratios for the first four years change relative to each other.

In summary, sensitivity analysis of intertemporal preferences shows that optimal hedging behavior of the representative farmer is sensitive to intertemporal preferences change. Risk aversion appears to have a larger effect on hedge ratios than time preference and intertemporal substitutability. Each of the preferences seems to have a different pattern of impact. But even in the separate analysis, the effect is often intertwined with influences from the other preferences due to relative value changes among them.

### ***Impacts of Market Institutions: Transaction Cost and Insurance Premium Loading***

Transaction costs related to futures contracts and insurance premiums are the major costs farmers pay for using hedging to reduce price risk and crop insurance to manage yield or revenue risks. To examine how these institutions affect farmers' risk management decisions, we set up different levels for transaction cost and premium loading, while other parameters in the model remain fixed. The impacts of transaction costs and insurance premium loading are studied in detail based on the base model. We also briefly discuss the impacts of these two factors based on results from other EU-type models in a later section.

Transaction costs are what farmers must sacrifice from current income to receive future market price protection if they choose hedging to reduce price risk. When transaction costs are charged, hedging has offsetting impacts. More hedging improves farmers' expected utility through price risk protection, but it also reduces utility by directly lowering current consumption.

Using the base model where all tools are included, we first let transaction cost vary from \$0/bushel to \$0.017/bushel, the current market level, at an increment of \$0.001. Because the CCP in government programs also has a market price protection function, we remove the CCP from the risk management pool and make hedging the only tool to reduce price risk. The summarized optimal hedge ratio changes are reported in Figure 3.4 and Table 3.1.

Figure 3.4 displays how the hedge ratios react to variations in transaction cost for the first year. A similar pattern is also exhibited in the second through fifth year, but the ratios are at decreasing levels as implied by Table 3.1<sup>13</sup>. The optimal hedge ratios generally display a decreasing trend as transaction costs increase, and the amount of the change is relatively small. From the upper panel in Table 3.1, we can see that 1% change in transaction costs result in about 0.3% change in the hedge ratio during the first year when the government CCP is included. The implication is that for our representative farmer, hedging is responsive but not very sensitive, to changes in transaction costs when government price protection is available.

Comparing the lower panel with the upper panel in Table 3.1 shows that after the CCP is removed, the hedge ratio increases by 45%, from 0.42 to 0.61, given the same transaction cost variation. Without the CCP, the ratios also appear to decrease faster from the first year to the fifth year. That is a steeper slope of the trend line. This suggests a smaller tolerance to a transaction cost increase without assistance from the CCP.

To find out the impact of premium loading charged for crop insurance purchases, we examined the optimal insurance coverage in response to changes in loading from 0% to 30%, with an increment of 5%. Our results based on the base model and various other portfolios show (Table 3.2), however, that farmers would always choose to buy the highest available coverage of 85%. One possible explanation for this could be that the crop insurance is heavily subsidized by

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<sup>13</sup> Complete results are in Appendix A.4.

the government. Therefore, although our representative farmer needs to pay more on premiums, the expected return from participating in the insurance program is still higher than the cost. Accordingly, it is beneficial to buy insurance at 85% rather than any lower coverage level.

In summary, the impact analysis of market institutions shows that farmers are more responsive to the changes in transaction cost than in insurance premium. But the responsiveness in hedge ratios to transaction cost is relatively inelastic, indicating hedging might not be a major consideration in farmers' risk management decisions. Our representative farmer would always choose to purchase insurance at the highest level 85%. Apparently the expected return due to crop insurance premium subsidies covers the expenses due to premium loading.

#### ***Impacts of Government Price Protection: Target Price and Loan Rate***

Apart from hedging, government programs also contain elements of market price protection. Base on values of the parameters for the target price ( $P_T$ ) and loan rate ( $L_R$ ) relative to the expected market price, farmers receive price protection. Here we study the impacts of these two parameters by changing their values hypothetically, while keeping the expected cash price based on simulated distribution fixed for the next five years.

The impacts of these two parameters based on base model optimization are combined in one graph as shown in Figure 3.5. The graph shows how optimal hedge ratios change as the government protection level varies over the next five years. The process of combining the impacts works as follows. First, when the target price changes from the current level of \$3.92/bushel down to \$2.86/bushel, the loan rate remains at \$2.86/bushel. Therefore, the price range from \$3.92 to \$2.86 on the horizontal axis represents impacts from reducing the CCP's target price. When the target price drops below \$2.86, the CCP actually has a zero value and no longer plays a role in hedging decision. Thereafter, the loan rate varies from \$2.86 to \$0,

reflecting a decreasing level of protection from the LDP. When the loan rate finally reaches \$0, the LDP drops out of the hedging decision. No more direct price protection is available in government programs at this point.

From Figure 3.5, the pattern for target price variation is different than for the loan rate. From \$0 to \$2.86, hedge ratios decrease at an increasing rate as more price protection from government programs becomes available, implying an increasing substitution effect of LDP for hedging. When the loan rate is \$0, hedging is the only way to reduce price risk and the optimal hedge ratio for each year reaches the highest possible level of around 0.78. This maximum level is determined by the correlation between the cash and futures prices as well as the transaction cost level. Also as the loan rate increases, hedge ratios for the later years drop faster than those for the earlier years. Again, this is because early resolution of risk is preferred to late resolution.

From \$2.86 to \$3.92, the impact of the CCP's target price enters the hedging decisions but takes effect step by step. From a target price level of \$2.86 to almost \$3.52, the CCP does not impact hedging. The hedge ratios essentially remain at the same level. This is from the impact of the \$0.52 direct payment ( $P_D$ )<sup>14</sup>. Starting from \$3.52, the target price begins to exceed the threshold. Hedge ratios drop rapidly until finally reaching 0.30~0.42, indicating an increasing influence from CCP on the risk management decisions and a greater substitution of CCP for hedging.

In summary, optimal hedging is sensitive to variations in the LDP loan rate and the CCP target price. Results indicate a strong substitution effect from the government LDP and CCP for

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<sup>14</sup> As defined early, CCP takes effect after a “trigger price” is reached, i.e.  $CCP_t = 0.85 \times 0.935 \times E_{t-1}(Y_t) \times \max[0, P_T - P_D - \max(P_t, L_R)]$  therefore  $CCP > 0$  only if  $P_T - (P_D + \max(P_t, L_R)) > 0$ . When  $P_T$  is greater than  $L_R$  but  $(P_T - \max(P_t, L_R))$  less than  $P_D$  of \$0.52, CCP always yields a zero value. So there is no income improvement to the farmer.

hedging in terms of price risk protection. The impacts appear somewhat stronger in the later years than in the early years.

### ***Relative Impacts of Hedging, Crop Insurance, and Government Programs***

We consider four major cases, \$0.017 vs. \$0 hedging transaction cost, paired with 0% and 30% insurance premium loadings respectively, as shown in Table 3.2 and 3.3. Under each case, we set the base portfolio scenario as a full set of futures contract, crop insurance, and all three government programs (DP, LDP, CCP). Then from the base scenario, we reduce one instrument at a time to study the marginal effect of that instrument.

We design five risk management portfolios for the farmer. In addition to the optimal hedge ratios and crop insurance ratios, we also compute a CE using equation (3.4). CE serves not only as a measurement of welfare improvement, but also as a criterion to assess the relative effectiveness of the tools to the farmer.

We start with the most complete set of risk management tools. In the base scenario with a \$0.017/bushel transaction cost (Table 3.2, upper panel), optimal hedge ratios range from 25% to 32% over years. The CE of this full portfolio is \$62.28, the highest among all portfolios. As we decrease the availability of government programs by taking away CCP first and then LDP, hedge ratios generally increase from around 30% to 40% to around 60% to 75%, to cover the extra risk. Correspondingly, without the support of CCP and LDP, the CE of the portfolios also decreases a lot by more than 50% from \$62.28 to \$34.58. When the DP is also eliminated, hedge ratios increase very slightly instead, which is due to the farmer's tightened budget on transaction costs. Without any government payments, the farmer has less wealth and is not willing to pay the futures transaction cost. There is a different result for the scenario when there is no transaction cost (Table 3.2, lower panel). The hedge ratios are about the same with or without the DP.

Although the insurance premium loading doesn't seem to affect the optimal coverage level, it affects the farmer's evaluation of the welfare improvement due to insurance. Higher premium loading yields a smaller value of the insurance product in all portfolios..

As we take away the payment programs one by one, the change in CE discloses information about the specific values of each program. For example, the difference between the first two portfolios indicates a CCP value of \$13.46 (62.28-48.82) to the farmer. We compute all these values and report them in Table 3.3. Among the three government programs, the DP has a highest value, while the CCP has a value close to the LDP. In total government programs account for \$57.47, which is more than 90% of the total value of the base portfolio (\$62.68).

When we take away all government programs, the farmer relies on hedging and insurance. He or she can still find a hedging path and rely on the highest 85% insurance coverage to manage risks but achieves a much lower welfare level (CE=\$4.81). The value of hedging can be calculated when we consider another portfolio of only crop insurance and government programs (CE=62.20). The difference between the CE of this last portfolio and that of the comprehensive base portfolio (\$62.28) yields \$0.08. The low value of hedging is not too surprising considering farmers' low participation rates. However, the value is quite low even though they hedge at a significant percentage. Compared to insurance and government programs, futures is the only tool that does not receive any subsidy while paying a transaction cost. Considering that insurance is limited to yield insurance, the value of hedging may go even lower when revenue insurance is included. Correspondingly, when the value of CI is computed by subtracting the total government programs' value from this last value, it turns out to be \$4.73 (\$62.20-\$57.47) under 0% premium loading and \$4.60 (\$62.07-\$57.47) under 30% premium loading. These values are a lot less than the individual government programs but still

significantly larger than hedging in the value of the full portfolio. This indicates that to the farmer, an income transfer in terms of subsidy is more valuable than risk reduction of a non-subsidized instrument like hedging.

Next we take off the transaction cost so hedging has no cost to the farmer. We see from Table 3.2 lower panel that optimal hedge ratios generally increase significantly. The rate of the increase slows down when hedge ratios get close to 79%. The values of the portfolios also increase slightly when the farmer saves money on hedging. The optimal insurance coverage ratio still stays at 85% with both 0% and 30% premium loadings, implying that the gain from saving on hedging still cannot replace the possible loss from lower insurance coverage.

The CE values of each risk management tool change slightly too (Table 3.3). The value of hedging goes up by about 35%. The insurance and government programs have slight changes in CE values. Despite that, the ranking of the values for these tools stays the same, that is, government programs (DP + LDP + CCP) > CI > hedging.

## **VI. Concluding Remarks**

We investigate the impacts of intertemporal preferences, hedging and crop insurance costs, and U.S. government payment programs on a PNW wheat producer's dynamic risk management behavior. By using the GEU model, we solve the dynamic optimization problem numerically based on simulated yield and price data for 2004 through 2008.

The GEU framework has flexibility in the parameterization of the farmer's preferences towards risk, timing, and intertemporal substitutability of consumption. We employ this feature to examine the impacts of changes in these preferences on farmers' optimal hedging and crop insurance participation. Preference impact analysis implies that optimal hedging behavior of the

representative farmer is sensitive to intertemporal preferences changes. Risk aversion appears to have a larger effect on hedge ratios than time preference and intertemporal substitution. Each of the preferences has its own impact pattern. But even in the separate analyses, the effect is often intertwined with influences from the other preferences due to relative value changes.

The market institution impact analysis shows that hedging transaction costs negatively affect optimal hedge ratios and reduces the farmer's welfare level. When crop insurance is coupled with a premium subsidy, even an insurance premium loading of 30% is not enough to keep the farmer from purchasing the highest available level of insurance coverage. However, the premium loading definitely reduces welfare. The impact analysis of government price protection parameters, the target price and loan rate, indicates that both of them are influential in hedging decisions. The corresponding government LDP and CCP have increasing substitution impact on hedging as the price protection level increases. The relative impact analysis of current risk management tools shows both crop insurance and government programs are influential to the farmer's welfare improvement. Hedging has very limited contribution. In terms of the ranking of the value of these tools, the government programs (DP + LDP + CCP) have a greater effect on farmers' welfare than crop insurance, and crop insurance outperforms hedging. Yield insurance has a greater value than DP, LDP, or CCP separately, but less than the three combined. Among the three government programs, the DP has higher a value than the respective values of the LDP and the CCP for the representative farmer.



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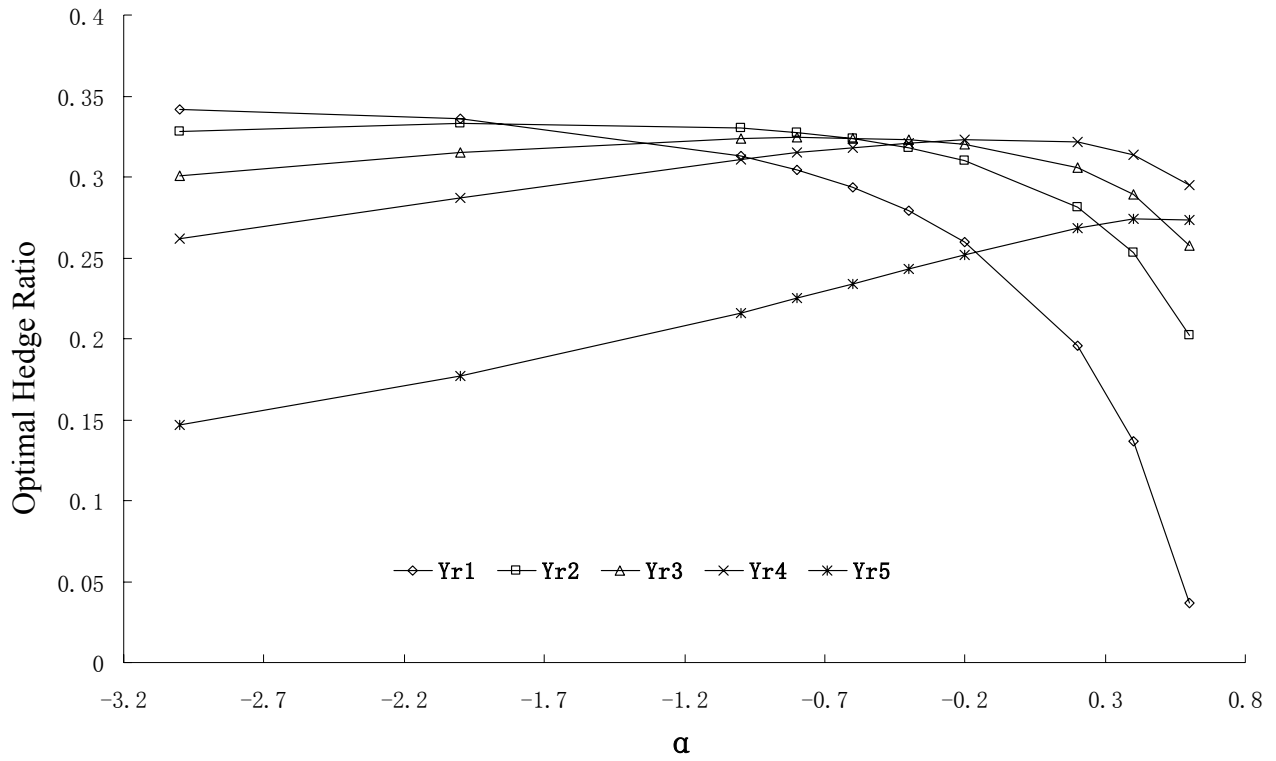
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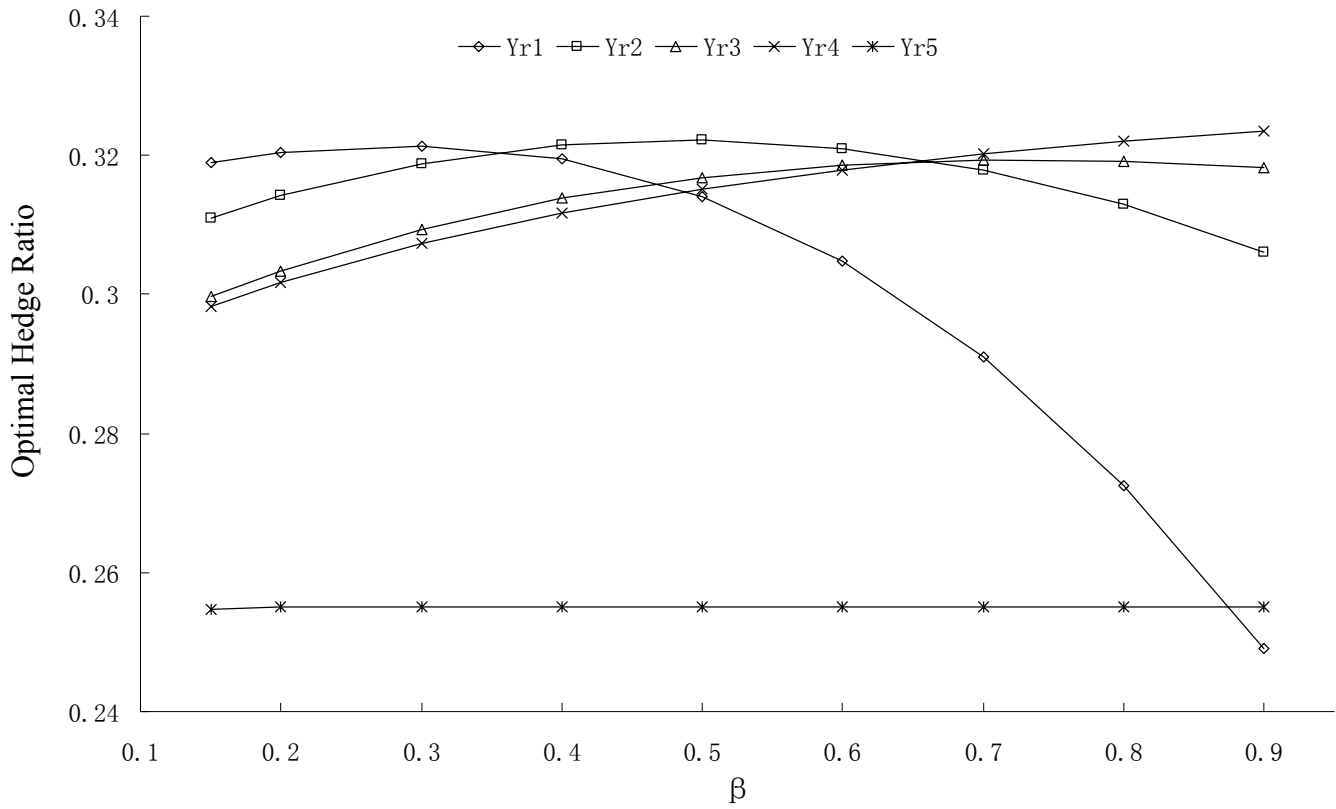
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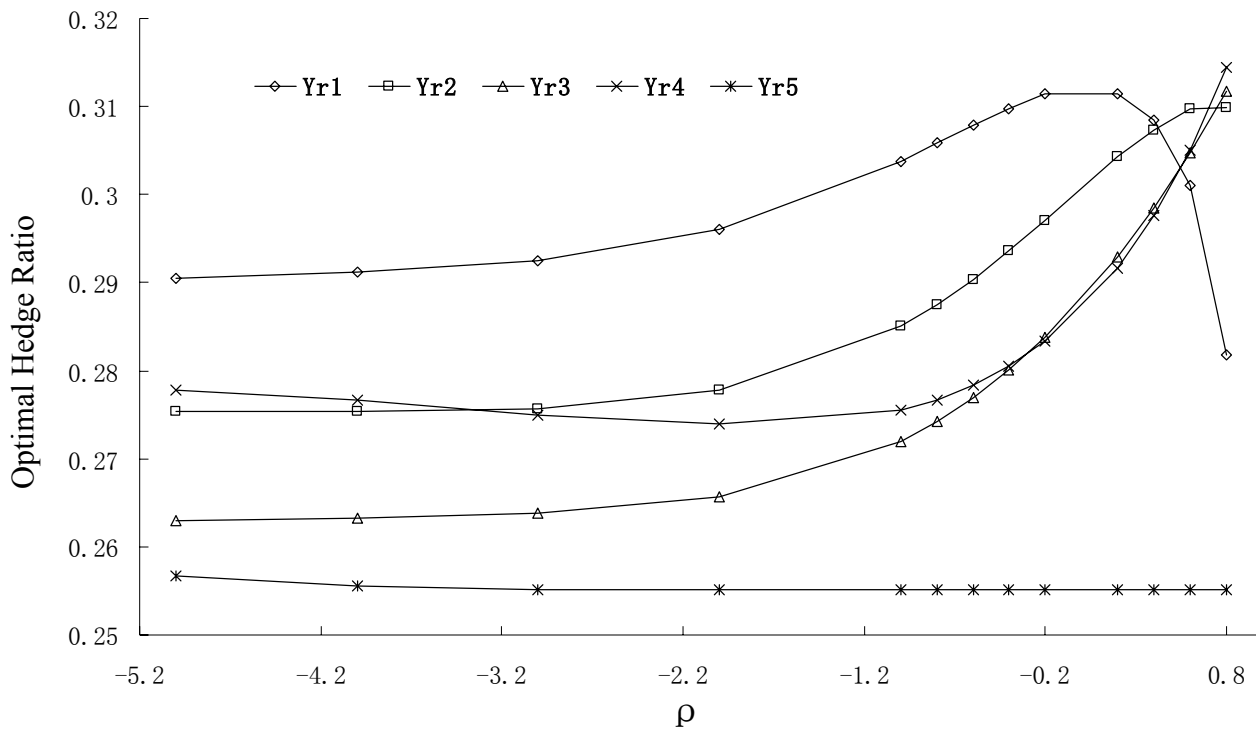
**Figure 3.1. Sensitivity of Optimal Hedge Ratios in Response to Risk Aversion**



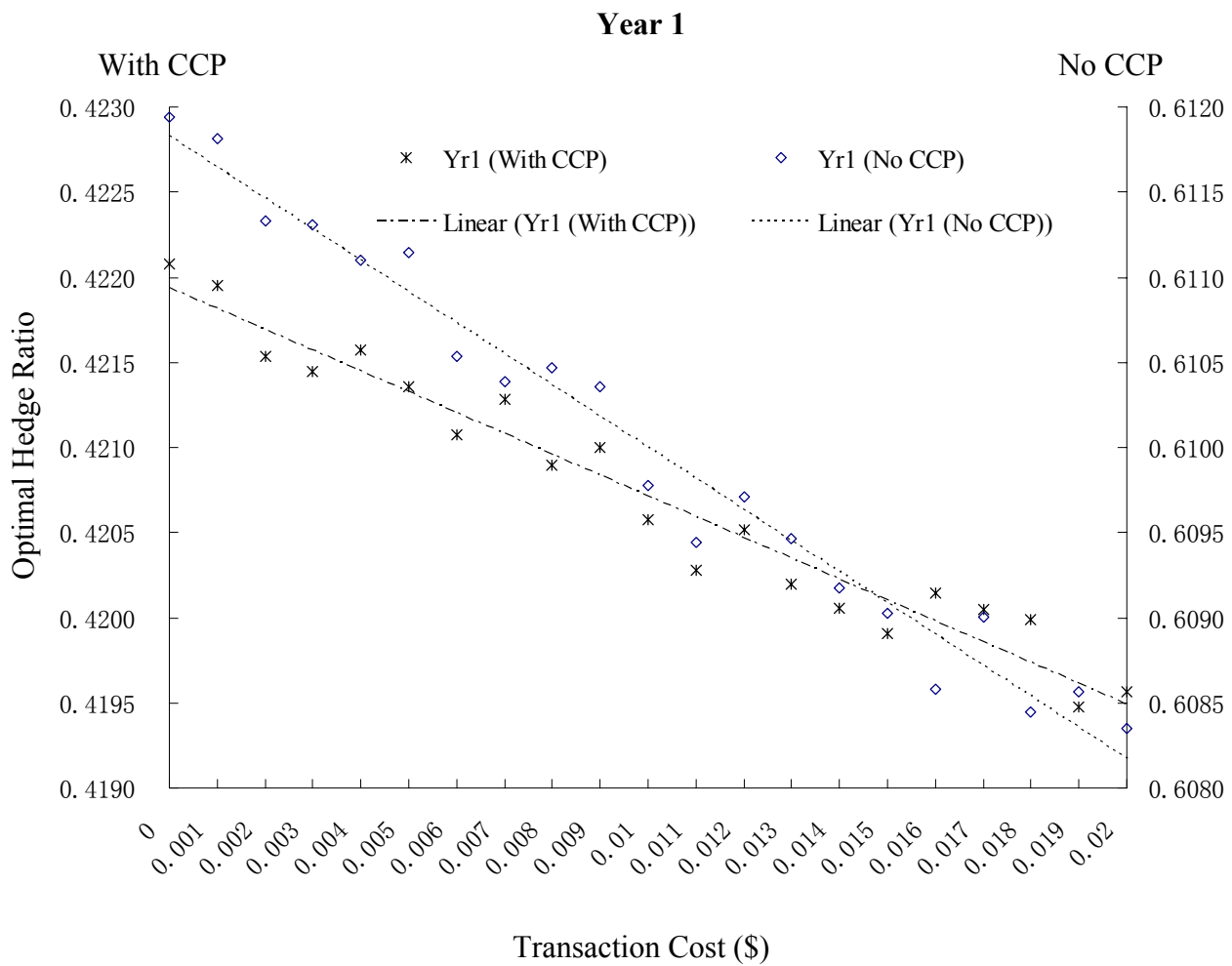
**Figure 3.2. Sensitivity of Optimal Hedge Ratios in Response to Time Preference**



**Figure 3.3. Sensitivity of Optimal Hedge Ratios in Response to Intertemporal Substitutability**

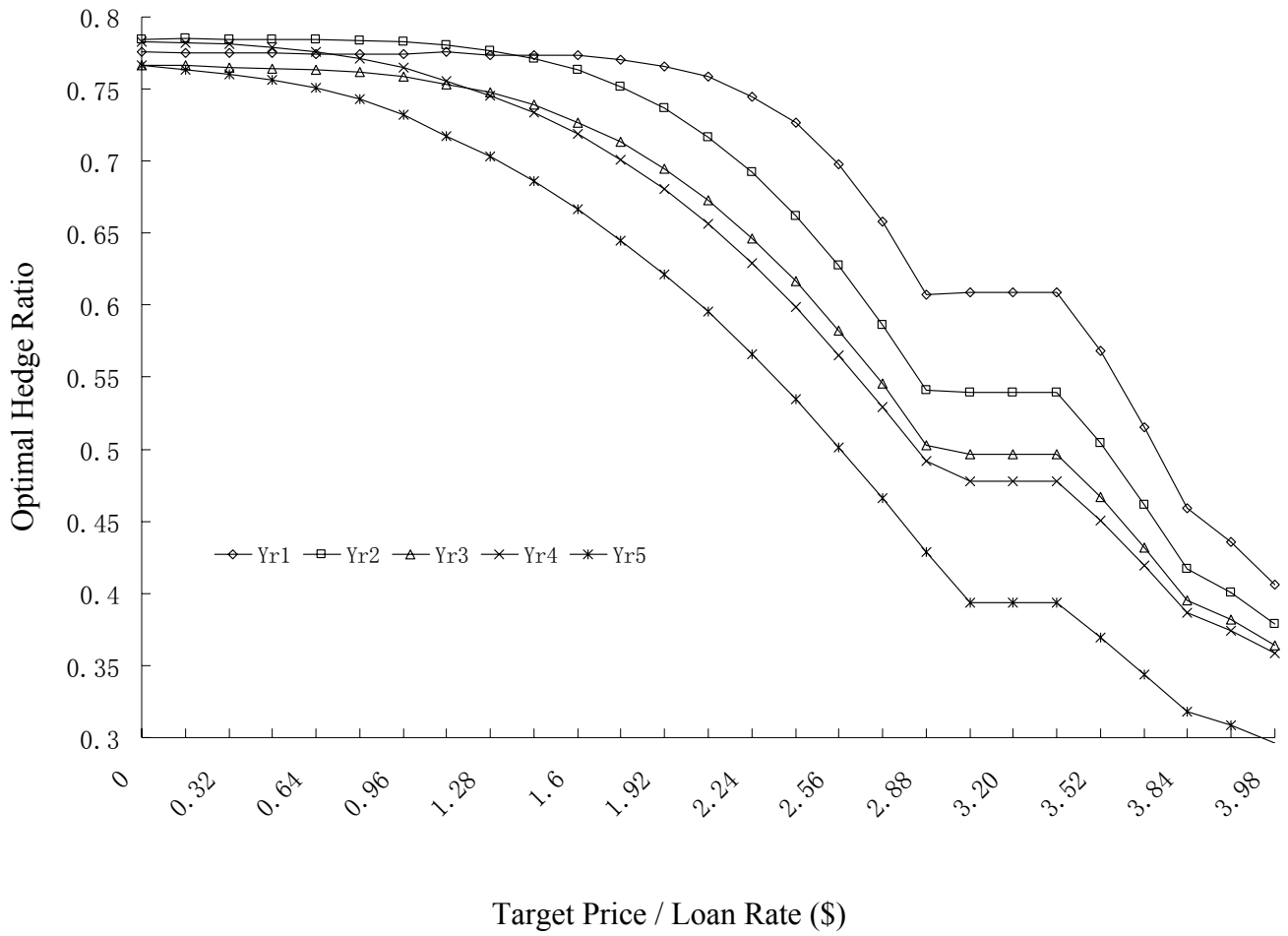


**Figure 3.4. Sensitivity of Optimal Hedge Ratios in Response to Transaction Cost**





**Figure 3.5. Sensitivity of Optimal Hedge Ratios in Response to Target Price / Loan Rate**



**Table 3.1. Summarized Optimal Hedge Ratio in Response to Transaction Cost**

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Optimal Hedge Ratios (With CCP)

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	Year1	Year2	Year3	Year4	Year5
Mean	0.4207	0.3856	0.3651	0.3520	0.2677
Max	0.4221	0.3862	0.3655	0.3523	0.2679
Min	0.4195	0.3849	0.3648	0.3517	0.2676
Range	0.0026	0.0013	0.0008	0.0005	0.0002

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Optimal Hedge Ratios (No CCP)

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	Year1	Year2	Year3	Year4	Year5
Mean	0.6100	0.5398	0.4972	0.4780	0.3933
Max	0.6119	0.5405	0.4976	0.4784	0.3935
Min	0.6083	0.5389	0.4967	0.4776	0.3932
Range	0.0036	0.0016	0.0009	0.0008	0.0003

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Note: The hedging transaction cost varies from \$0/bushel to \$0.02/bushel.

**Table 3.2. Impacts of Market Institutions and Government Policies on  
Farmers' Optimal Risk Management Portfolio**

Alternative Portfolios	Hedge Ratio					Crop Ins.	0% Premium	30% Premium
						Coverage	Loading	Loading
	Year1	Year2	Year3	Year4	Year5	Year1-5	CE(\$)	CE(\$)
<i>With Transaction Cost (\$0.017/Bushel)</i>								
H & CI & G(DP, LDP, CCP)	0.25	0.31	0.32	0.32	0.26	0.85	62.28	62.15
H & CI & G(DP, LDP)	0.39	0.44	0.44	0.44	0.38	0.85	48.82	48.69
H & CI & G(DP)	0.28	0.57	0.65	0.72	0.74	0.85	34.58	34.45
H & CI	0.32	0.59	0.66	0.72	0.74	0.85	4.81	4.68
CI & G(DP, LDP, CCP)	--	--	--	--	--	0.85	62.20	62.07
<i>Without Transaction Cost (\$0/bushel)</i>								
H & CI & G(DP, LDP, CCP)	0.42	0.39	0.37	0.35	0.27	0.85	62.68	62.54
H & CI & G(DP, LDP)	0.61	0.54	0.50	0.48	0.39	0.85	49.39	49.26
H & CI & G(DP)	0.78	0.79	0.77	0.79	0.77	0.85	35.44	35.31
H & CI	0.78	0.79	0.77	0.79	0.77	0.85	5.67	5.54
CI & G(DP, LDP, CCP)	--	--	--	--	--	0.85	62.20	62.07

Note: The base portfolio is the portfolio that includes all risk management tools, i.e. H & CI & G(DP, LDP, CCP).

**Table 3.3. Evaluation of Risk Management Instruments**

Alternative Instruments	\$0.017/bushel Futures Transaction Cost		\$0/bushel Futures Transaction Cost	
	\$ 0% premium loading	30% premium loading	\$ 0% premium loading	30% premium loading
Gov't programs (total, \$)	57.47	57.47	57.00	57.00
CCP	13.46	13.46	13.29	13.29
LDP	14.24	14.24	13.94	13.94
DP	29.78	29.78	29.77	29.77
Crop Insurance (MPCI, \$)	4.73	4.60	5.20	5.07
Hedging (\$)	0.08	0.08	0.48	0.48

## CHAPTER 4

### PRICE BEHAVIOR AND INTERNATIONAL MARKET INTEGRATION: A COMPARISON OF CHINA AND US WHEAT FUTURES

**Abstract:** China's 10-year-old wheat futures market, the China Zhengzhou Commodity Exchange (CZCE) has been in stable development since establishment and is expected to be integrated into the world market after China joined the WTO. This paper compares the price behavior of CZCE with that of the Chicago Board of Trade (CBOT) in the US using ARCH/GARCH based univariate and multivariate time series models. Results show both markets can be modeled by an ARCH(1) or a GARCH(1,1) and the models have a better fit when conditional error variance is  $t$  distributed. The price series in CZCE and CBOT are interrelated but not cointegrated. The existing interrelationships between the two markets are significant and asymmetric. CBOT holds a dominant position in the interactions, while CZCE behaves more like a follower.

**Key words:** futures price, GARCH, integration, China, wheat

## I. Introduction

The emergence of agricultural commodity markets in China resulted from the market-oriented economic reform launched in the late 1970s. After about twenty five years, the reform not only turned China into the world largest wheat production and consumption country (USDA, 2004), but also lead to the formation of a market mechanism in China. Based on this market mechanism, more efficient institutions of exchange for agricultural products were created and developed. As a result, China's domestic market integration for major commodities across regions has been progressing steadily. This progress has been enhanced in recent years, after most barriers to cross-region trading and information flows were removed (Huang and Rozelle, 2004).

Agricultural commodity futures markets emerged in China in the early 1990's, when China was moving into an advanced phase of market-oriented economic reform. China's first exchange market, the China Zhengzhou Commodity Exchange (CZCE) was founded in 1990. Wheat futures trading started in May 1993. CZCE is the only exchange trading wheat futures contracts in the country today. In 1999, CZCE accounted for 50% in total trading value and 49% in total trading volume of all commodity exchanges in China. Since 1997, trading of wheat futures has experienced stable growth except for 1999 (Figure 4.1)<sup>15</sup>. In 2002, the total trading value amounted to 225.25 billion Yuan<sup>16</sup> and total trading volume was 18.27 million contracts.

After about 10 years of development, the wheat futures price in CZCE is on the way to

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<sup>15</sup> The low trading in 1999 was mostly affected by the regulatory change in CZCE, which was designed to discourage mung bean trading. As a result, mung bean trading declined sharply and disappeared in the following years.

<sup>16</sup> One US dollar equals about 8.3 Yuan.

becoming an important indicator of China's wheat price. The correlation between the spot price and futures price is as high as 0.96. A strong association exists between the wheat futures price of CZCE and that of Chicago Board of Trade (CBOT) in the United States (CZCE Report, 2001). China's wheat futures price became more important to the world after November 2001 when China obtained full membership in the WTO. Given the enhanced relationship between China's markets and the world market, China's integration to the world is on a fast track and has shown two-folded impacts. Facing challenges from major wheat exporters such as the US and Canada, China's previously over-valued domestic wheat price is expected to undergo a downward shift. The futures price in CZCE may increase in volatility due to a stronger linkage to the world commodity markets and the unpredictable factors in the world economy. Conversely less volatility may exist because irrational behavior of domestic traders that had a fairly strong influence on prices in the past (Durham and Si, 1999) will not be able to affect an integrated world market price.

Founded in 1848 and by far the largest and most developed agricultural commodity market in the world, the CBOT in the US has been playing a leading role in the world commodity market. The wheat futures price on the CBOT is highly volatile, and directly reflects supply and demand in both the US and world markets. The CBOT has been one of the most important wheat price indicators in the world market. In this paper, the CBOT wheat futures market is chosen to represent the world market. The integration of CZCE to the CBOT will be analyzed as an approximation of CZCE's integration into the world market.

This research is a quantitative assessment of China's wheat futures price performance and the integration of China's wheat futures market into the world market. The objective is to identify the best time series models to characterize the price behavior in both CZCE and CBOT,

and the interrelationship between them. We then use the identified models to compare price patterns in both markets and investigate the outlook of China's market integration to the world market. Specifically, this analysis will: 1) estimate and identify an appropriate ARCH/GARCH model for China's and US' wheat futures prices; 2) investigate the interrelationships between the two price series, including cointegration in the first moment and autoregressive heteroskedasticity in the second moment, in a multivariate framework; and 3) compare the price patterns between the two markets and assess the role of China's wheat futures market in the world market.

## **II. Previous Studies**

China's successful economic reform has drawn the world's attention for more than two decades. China's 2001 membership into the World Trade Organization (WTO) brought such attention to a new level. However, studies on China's agricultural commodity futures markets are quite limited, particularly with regard to wheat futures. Moreover, most of the existing studies are more descriptive and focus on regulatory and market development issues rather than quantitative investigations of futures prices. Such studies include Tao and Lei (1998); Fan, Ding and Wang (1999); and Zhu and Zhu (2000). A historical perspective on the development of China's futures market is shown in Yao (1998), which includes a detailed structural analysis of the commodity futures markets and the government's legislative and regulatory attempts.

Some quantitative analyses have been attempted in recent years. Williams, et al. (1998) investigated mung bean trading in CZCE to test for market efficiency. Durham and Si (1999) examined the relationship between the China Dalian Commodity Exchange (CDCE), another commodity futures market in China, and the CBOT soybean futures prices through a regression



model. Wang and Ke (2003) investigated information efficiency for the CZCE wheat and CDCE soybeans futures in a framework of cointegration between cash and futures markets. Despite that, quantitative studies dealing with the time series properties of price on China's wheat futures market, especially on the issue of world market integration, have not been found.

Modeling time series data usually starts from the moving average (MA) model, autoregressive (AR) model, or more generally, autoregressive integrated moving average (ARIMA) model for the first moment of the data. However, stochastic trend or unit root is discovered as a common property of many high frequency commodity price series (Ardeni 1989; Baillie and Myers, 1991). More complete but complicated price models focusing on the second- or higher-order moment variability were introduced in early 1980s. The autoregressive conditional heteroskedasticity (ARCH) model, developed by Engle (1982), allows the shocks in nearby earlier periods to affect the current volatility. The generalized ARCH, (GARCH) model (Bollerslev, 1986) allows, in addition, previous volatilities to affect current volatility, so that the volatility behaves like an AR process. ARCH and GARCH models have been widely applied in financial time series analysis (Bollerslev, Cho, and Kroner, 1992) as well as in agricultural commodity prices (Baillie and Myers, 1991; Yang and Brorsen, 1992; Tomek and Myers, 1993; Myers, 1994). Excess kurtosis, namely heavier tails compared to the normal distribution, is also found in commodity prices (Gordon, 1985; Deaton and Laroque, 1992; Myers, 1994).

Although ARCH and GARCH models can partially alleviate the excess kurtosis problem (Engle, 1982; Myers, 1994), empirical studies have shown that these models cannot capture all kurtosis impact if a normal distribution is assumed for the price innovations (Bollerslev, 1987; Baillie and Myers, 1992; Yang and Brorsen, 1992). One possible solution to this problem is to use the t-distribution instead of normal distribution to describe the price

innovations in the ARCH/GARCH models (Myers, 1994).

Based on the theoretical framework derived by Engle and Granger (1987), and the empirical test methods by Johansen and Juselius (1990, 1992), studies on international futures markets have started to focus on using cointegration as an indication of market integration. Cointegration is a phenomenon where multiple nonstationary variables are driven by some common stochastic trends. Yang, Zhang, and Leatham (2003) examined the price and volatility transmission in a three-variable system for the US, Canadian, and EU markets. They found no cointegration in the system. Bessler, Yang, and Wongcharupan (2003) examined the wheat futures markets in the US, Canada, Australia, EU, and Argentina, and found cointegration.

The present paper contributes to the existing literature on China's wheat futures prices in three ways. First, it incorporates both China's and US's wheat futures markets into a multivariate time series model so that the price interactions in the two markets can be studied simultaneously. Second, besides the interaction at the mean level as investigated in the cointegration studies, the interaction at the variance level is also carefully examined. Third, the assumed conditional error distribution of price changes is extended from normal distribution to  $t$ -distribution in a multivariate situation; therefore improvement of excess kurtosis can be examined and compared.

### **III. Models**

#### **1. Univariate Conditional Heteroskedastic Models**

We start with the univariate ARCH and GARCH models, which allow the volatility of error terms to change over time. An ARCH( $q$ ) model is commonly defined to include a mean

equation:

$$(4.1) \quad Y_t = X_t' \beta + \varepsilon_t, \text{ where } \varepsilon_t | \Omega_{t-1} \sim (0, h_t)$$

and a variance equation:

$$(4.2) \quad h_t = \omega + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2$$

where  $Y_t$  denotes the dependent variable;  $X_t$  denotes the vector of explanatory variables which can include a constant, a time trend, lagged dependent variables, and/or any (lagged) exogenous variables;  $t$  denotes the time period;  $\varepsilon_t$  is the error component in the ARCH model whose conditional distribution has a zero mean and time-varying variance  $h_t$ ;  $\Omega_{t-1}$  is the information set available at  $t-1$ ;  $\beta$  is the parameter vector for the exogenous variables;  $\omega$  ( $\omega > 0$ ) is the parameter for intercept in the variance equation; and  $\alpha_i$  ( $\alpha_i \geq 0$  and  $\sum_{i=1}^q \alpha_i < 1$ ) for  $i = 1, 2, \dots, q$  is the parameter for ARCH effect.  $\varepsilon_t$ 's are serially uncorrelated, however, their dependency lies on the second moment evolution.

A GARCH (p, q) model is defined in the same way except that:

$$(4.2') \quad h_t = \omega + \sum_{i=1}^q \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^p \gamma_j h_{t-j}$$

with  $\gamma_j$  for  $j = 1, 2, \dots, p$  as additional parameters for past volatilities;  $\omega > 0, \alpha_i, \gamma_j \geq 0$  and

$$\sum_{i=1}^q \alpha_i + \sum_{j=1}^p \gamma_j < 1.$$

The basic ARCH(q) model is a short memory process in that only the most recent q

shocks have an impact on the current volatility. The GARCH(p, q) model is a long memory process, in which all the past shocks can affect the current volatility indirectly through the  $p$  lagged variance terms.

## 2. Multivariate Conditional Heteroskedastic Models

Multivariate ARCH and GARCH models allow more than one series to be modeled together so that interrelation lies between different series can be examined and tested through cross equation parameter constraints.

An  $m$ -variate GARCH(P, Q) model can be defined as:

$$(4.3) \quad Y_t = BX_t + \varepsilon_t, \text{ where } \varepsilon_t | \Omega_{t-1} \sim (0, H_t)$$

$$(4.4) \quad H_t = W + \sum_{i=1}^Q A_i (\varepsilon_{t-i} \varepsilon'_{t-i}) A_i' + \sum_{j=1}^P \Gamma_j H_{t-j} \Gamma_j'$$

where  $Y_t$  is now an  $m \times 1$  dependent variable vector;  $B$  is the coefficient matrix corresponding to the explanatory variable vector  $X_t$ ;  $\varepsilon_t$ , the error vector, is conditionally distributed with a mean of an  $m \times 1$  null vector and an  $m \times m$  variance-covariance matrix  $H_t$ ;  $W$  is an  $m \times m$  parameter matrix for the constant terms, and  $A_i$  and  $\Gamma_j$  are  $m \times m$  parameter matrices for GARCH coefficients. By definition, the ARCH(Q) model is a special case of the GARCH(P,Q), when the coefficient matrices for the past variance-covariance matrices,  $\Gamma_j$ 's, are set at zeroes.

Alternative definitions of the variance equations and restrictions on matrices  $A_i$  and  $\Gamma_j$  exist, which lead to different versions of multivariate ARCH/GARCH models. The above defined model allows each element of the current variance-covariance matrix  $H_t$  to be affected by all elements of the past variance-covariance matrices and/or the squared error matrices. This

is called the BEKK model (Engle and Kroner, 1995). Other commonly used models, like the constant conditional correlation (CCC) model (Bollerslev, 1990) and the diagonal-vec (DVEC) model (Bollerslev, Engel, and Wooldridge, 1988), have simpler forms with different assumptions on parameters.

The variance equation in a CCC model has the following form:

$$(4.4') \quad h_{mm,t} = \omega_m + \sum_{i=1}^q \alpha_{mi} \varepsilon_{m,t-i}^2 + \sum_{j=1}^p \gamma_{mj} h_{mm,t-j}$$

$$h_{mn,t} = \rho_{mn} \sqrt{h_{mm,t} h_{nn,t}}, m \neq n$$

where  $h_{mn,t}$  is the  $mn^{\text{th}}$  element in  $H_t$ , and  $\rho_{mn}$  is the constant correlation between  $h_{mm,t}$  and  $h_{nn,t}$ .

With an imposed constant correlation coefficient on the independent univariate ARCH/GARCH models, the CCC model reduces the number of parameters to be estimated. However, this model only allows the conditional variances to evolve based on their own past levels and past shocks, and the relationship between one another is constrained to null and cannot be revealed.

The DVEC model defines the variance equation as:

$$(4.4'') \quad H_t = W + \sum_{i=1}^Q A_i \odot (\varepsilon_{t-i} \varepsilon'_{t-i}) + \sum_{j=1}^P \Gamma_j \odot H_{t-j}$$

where  $\odot$  is the Hadamard product operator.  $A_i$  and  $\Gamma_j$  are restricted to be symmetric matrices.

This model allows each element of the current variance-covariance matrix  $H_t$  to be affected only by its own past values and/or corresponding element in the past squared error matrices. Similar to the CCC model, information about the relationships between variances of different series is not available in the DVEC form. Furthermore, when the parameter matrices are set to be diagonal, the model will degenerate into separate univariate models.

#### IV. Data Description

The CZCE price data in the study are collected from CZCE's online database at <http://www.czce.com.cn>. The CBOT data are collected from <http://www.turtletrader.com>. The daily settlement price series for the September wheat contracts from January 4, 2000 to September 13, 2002 are used for both CZCE and CBOT series<sup>17</sup>. Prices are taken as continuous for each trading day. A switching-contract dummy variable,  $SD_t$ , is introduced in the explanatory variable vector X in addition to the constant term for both series to indicate when the price series switches from an old contract to a new one. The switching points are set at the last trading day of the old contract following the method as in Myers and Hanson (1993)<sup>18</sup>.  $SD_t$  equals 1 at the switching points and 0 otherwise.

The time-series plots of CZCE and CBOT prices are given in Figure 4.2. Both series show strong nonstationarity and stochastic trend, while CZCE prices look more chaotic than CBOT prices. For both price series, the sample autocorrelation functions show very slow exponential decay, and the sample partial autocorrelation functions show a large spike in the first lag. The augmented Dickey-Fuller (ADF) unit root test yields a P value of 0.60 for CZCE prices and 0.90 for CBOT prices, confirming the existence of a unit root. Therefore, the first difference is taken.

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<sup>17</sup> The original data are in Yuan per metric ton for CZCE prices and in US dollar per bushel for CBOT prices. To make the two data series directly comparable in our study, we converted CBOT data into Yuan per metric ton using constant factors, one metric ton equaling 36.74 bushels of wheat, and the exchange rate held constant at 8.2775.

<sup>18</sup> For CBOT data, trading of the September 2000 contract started in July 2000. These early prices were not included until September 2001 when the September 2000 contract expired. CZCE data are arranged similarly. The old contract trading prices are chosen for this overlapping period because the old contracts are traded more actively than the new one during the period.

From the time series plots (Figure 4.3) of the squared first difference data, evidence of a time-varying volatility pattern is visible in the CBOT series. That is, big changes are often followed by other big ones and small changes followed by small ones. This pattern is consistent with the ARCH/GARCH processes. Furthermore, the P values of Portmanteau Q statistic and the LaGrange Multiplier statistic, for testing  $H_0$ : no ARCH effect, are all less than or equal to 0.0001 for the first twelve lags on CBOT prices, indicating a strong ARCH effect. For our selected CZCE prices, however, the two statistics are not significant.

A normality check of CZCE and CBOT price changes provides strong evidence against normality. For CBOT price changes, the kurtosis coefficient is 1.80<sup>19</sup>, indicating the distribution has fatter tails than the normal distribution. The skewness coefficient is 0.24, close to zero, meaning it is quite symmetric. The distribution of CZCE price changes is also quite symmetric with the skewness coefficient of -0.57 but even fatter tails. The kurtosis coefficient is 6.67. These coefficients indicate the non-normality is mostly caused by excess kurtosis rather than the skewness.

## **V. Results**

### ***1. Univariate Analysis***

In this section, we study the price performances of CZCE and CBOT separately. Due to the existing unit root, first differences of the data are fit into alternative time series models. The mean equation of the model is defined as price change dependent on the constant term and the contract switching dummy, SD. A univariate framework is applied to find the best specifications of the ARCH/GARCH processes. The GARCH procedure in the GARCH module of S-PLUS is

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<sup>19</sup> A normal distribution has both skewness and kurtosis at 0 as a benchmark.

used to estimate these models. For the visible heavy tails of the price distributions, we estimate price models under both normality and t distributions. Results based on the two distributions are examined and compared.

#### *Selection of Model Specification*

Alternative specifications in terms of the lags of the ARCH/GARCH models are assumed. Two goodness-of-fit criteria, Akaike Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (BIC), along with significance criterion, are used to select the best model. Model fitting results show that ARCH(1) has the best fit for both CZCE and CBOT price changes under the normality assumption.

When estimating the above models, however, the Shapiro-Wilk and Jarque-Bera statistics for normality test reject the normality assumption in all cases. It confirms what we observed in the earlier normality check in the data section, and suggests a change of distribution is necessary. Following the existing empirical literature, we assume the error terms in the mean equation are t distributed with mean 0 and variance  $h_t$ , i.e.  $\varepsilon_t | \Omega_{t-1} \sim t(\nu)$ , where  $\nu$  denotes the degrees of freedom. With an obvious gain in the goodness-of-fit, the best models under the t-distribution are ARCH(1) for CBOT and GARCH(1,1) for CZCE.<sup>20</sup>

#### *Estimation*

Table 4.1 gives the estimation results of the choice models for CZCE and CBOT under both normal and t distributions. In general, the significance and sign of each parameter are consistent between the two sets of results. The main difference lies in the magnitude, or weight, of the estimated coefficients in the mean and variance equations. The models capture more contract switching and ARCH/GARCH effects when the conditional distribution is t.

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<sup>20</sup> Complete model fitting results are in Appendix B.1.



From the results, we see both CZCE and CBOT price changes contain no drift. The contract switching has insignificant and negative effects on CBOT price changes. But a significant and positive contribution is observed for CZCE price changes, indicating a jump-up of the price from the mean at the switching point in the CZCE<sup>21</sup>. In all the ARCH(1) models for CBOT and CZCE, the ARCH coefficient has a significant but relatively weak impact on the variance when compared with the intercept term. In the GARCH(1,1) for CZCE under t, however, the influence from the intercept drops enormously. Both GARCH and ARCH coefficients are significant, and the GARCH coefficient is a lot more influential, implying a large part of the current volatility in CZCE is due to the last period volatility.

## ***2. Multivariate Analysis***

Multivariate analysis allows both price series to be estimated simultaneously. As a result, cross market relations that cannot be detected in the univariate analysis can now be captured. In our multivariate version of the models, the mean equation still follows the same structure as in the univariate case, but the variance equation becomes a system of equations.

### *Nonsynchronous trading*

The wheat futures trading in the CZCE is not synchronous to the trading in the CBOT because CZCE and CBOT are in different time zones. There is no overlap in trading hours between the CZCE and CBOT. However the multivariate model setting implies synchronicity of the price movements in the markets. Therefore it is necessary for us to check for any nonsynchronous effect before applying the multivariate models.

When CZCE trading closes at 3:00pm Beijing time, CBOT trading on the same day won't start until ten (nine under daylight saving time) and a half hours later. Although the price

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<sup>21</sup> At the switching points, the estimated mean equation becomes  $\Delta P_t = \hat{\alpha} + \hat{\delta} + \hat{\varepsilon}_t$ , where the right-hand-side of the equation represents the level of price changes when the contract switches.

for the same day trading is indexed by the same  $t$  for both CZCE and CBOT in our multivariate model, there are actually referring to two different time slots with about ten hours in between. Information about trading in CZCE on the same is completely available before CBOT trading opens. Given this timeframe, wheat futures trading in CBOT could possibly be affected by the information in CZCE and such impact may be reflected in the price movements. Similarly, when the CBOT closes trading at 1:15pm, it is only about three hours before the CZCE trading starts on the following day. Therefore CBOT price at time  $t-1$  can affect the CZCE price at time  $t$ .

On the other hand, however, although the CZCE same-day price and trading are known information to CBOT traders, the information itself may not be influential enough to affect the CBOT price. The CBOT is a much larger market than the CZCE with participants from worldwide and way higher trading volume. It is also possible that the impact, if any, of CZCE is relatively insignificant therefore it cannot really affect CBOT price behavior. Moreover, depending on the degree of CZCE market integration to CBOT, the information may or may not be applicable to CBOT trading. However, this situation may not be the case for the impact of the CBOT on the CZCE.

The examination of the nonsynchronous trading effect in the prices not only provides information necessary for further multivariate model fitting, but can also show evidence about the degree of integration of the CZCE to the CBOT. The estimation results are summarized and reported in Table 4.2. In general, no significant nonsynchronous trading effect is detected in the price changes between the two markets.

In Table 4.2, we list the estimation results using two separate autoregressive regression models, one for each market. We incorporate prices at two time lags,  $t$  and  $t-1$ , for both CBOT and CZCE. For CBOT price at  $t$ , the nonsynchronous trading effect from CZCE is reflected in

the coefficient in front of the last trading CZCE price indexed by  $t$ . For CZCE, the effect is mainly reflected in the coefficient associated with the last trading CBOT price indexed by  $t-1$ . As the results show, both coefficients are not significant, and it appears that the impact from CBOT on CZCE is generally stronger than that from CZCE on CBOT.

### *Cointegration test*

In order to identify the possible interrelationships that exist in the co-movement of the price levels, we first conduct the cointegration test on the original prices of CZCE and CBOT wheat futures. We then go on to examine the second moment (or volatility) relation. According to the ADF unit root test, both price series are integrated to order one, satisfying conditions for the cointegration test. Proceeding with the Johansen's cointegration test, however, we fail to reject the null hypothesis of no cointegration. Results indicate our data on CZCE and CBOT wheat futures prices have no cointegrating relation on the first moment, and a vector regression model is appropriate for the following time series analysis. Here the dependent variable vector is the first difference of prices, and the independent variable vector includes constant and two contract switching dummy variables.

### *Selection of Model Specification*

To fully disclose the interrelations between CZCE and CBOT wheat prices, we apply three types of multivariate GARCH models, BEKK, CCC, and DVEC, to estimate the CBOT-CZCE bivariate series under both normal and  $t$  distributions<sup>22</sup>. By definition, the BEKK model contains information about the cross-market ARCH/GARCH effects. The CCC and DVEC models are simplified multivariate GARCH models with different model structures. Since these

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<sup>22</sup> Although usually the joint  $t$  distribution is not well-defined, unlike its normal counterpart, it is defined in a certain way in S-Plus GARCH module (S+ GARCH User's Manual, pp107-108, Mathsoft, inc., March 2000). This definition is followed in our analysis.

two models have different ranks in restrictiveness and robustness, we include both in the estimation for comparison purposes. The MGARCH procedure in the GARCH module of S-PLUS is used for analysis in this section. The results show that GARCH(1,1) in the DVEC and CCC forms has a better fit under both normal and t distributions, while in BEKK form ARCH(1) performs better (Table 4.3).

### *Estimation*

Information about the interactions between elements in the conditional variance matrix and relationships between the price changes of China and US wheat futures are now reflected in the estimates (Table 4.3).

When the BEKK model is fitted with a normal distribution, CZCE price changes appear to have a small drift which is not evident for the CBOT data. The coefficient matrix  $\Lambda$  for the switching dummy vector provides full information about within and cross equation relationships of contract switching in the two markets. For the within market effect, the CZCE switching dummy has a significant positive impact on the mean of price changes, similar to the univariate case. The CBOT dummy has a significant positive impact on its price changes, quite different from the univariate case. The cross effects, however, are both statistically insignificant, implying the interactions of contract switching between the two markets are weak.

The variance equation estimates do not directly reflect within- and cross- market effects on volatilities. These effects can only be shown by certain combinations of these estimates. In the Appendix B.2 we provide a detailed derivation of such combinations. The calculated estimated effects are reported in Table 4.4. When a normal distribution is assumed, current volatility of CBOT price changes is positively correlated with the last period shock in its own market and that in the CZCE. The own market effect of 0.1132 dominates the cross market effect

by a ratio of 15:1. Therefore the volatility in the CBOT is mostly affected by the previous shock in its own market. The previous shock in CZCE has very limited influence on the volatility in CBOT. The volatility in CZCE is even more dominated by the own market effect rather than a cross market effect. The ratio increases to 28:1.

The insignificance of both  $A_{uv}$  and  $A_{vu}$  indicates that the cross impact in the variance equation may not exist, and the BEKK is not superior to DVEC or CCC. The smaller AIC's and BIC's of DVEC and CCC also indicate they actually have a better fit.

From Table 4.3, in the bivariate DVEC form of GARCH(1,1), when the underlying conditional distribution is normal, the intercepts in the mean equation are consistent with the univariate cases. This suggests neither of the series shows a significant drift in prices. The own market contract switching dummies have a similar pattern as in the BEKK model. The cross equation terms show that contract switching in the CBOT has a significant negative influence on price changes in the CZCE, while switching in the CZCE does not affect the CBOT price significantly. The contract switching dates are different for the CBOT and CZCE. Switching occurs around September 15 for the CBOT, and one week later for the CZCE. This implies when the old contract expires at CBOT, switching to a new contract in the CBOT enhances the decreasing trend of old contract prices in the CZCE. But contract switching in the CZCE doesn't have a comparable effect on CBOT new contract prices when it occurs one week later.

In the variance equation, only CZCE volatility has a significant drift. For CBOT price changes, the last period volatility has much more influence on current volatility than the last period shock, which indicates the CBOT price has a long memory. Volatility has an estimated coefficient of 0.96 while shock has an estimate of 0.03. The own market effect of volatility for CZCE price changes shows a similar pattern. The gap between the influences of last period

volatility and last period shock seems smaller in the CZCE. This indicates that the CZCE price has a shorter memory than the CBOT price, so that a shock tends to have a larger relative impact on price for the next period. This result indicates prices in CZCE are apt to be more volatile, even chaotic.

Estimation results from the CCC model are generally very close to those from the DVEC. In terms of model fit, the DVEC under a normal distribution outperforms both CCC and BEKK with a smaller AIC and BIC.

When the underlying distribution is  $t$ , results are different. Particularly, all the parameters for interaction terms between the two markets, including the switching dummy and covariance, are insignificant. This may indicate the two markets do not demonstrate significant interactions.

#### *Market Integration of CZCE*

The integration of the CZCE into the world market, especially the CBOT, has been an interesting issue to many researchers as well as government officials since the CZCE's establishment. Actually, there is a general belief that CZCE prices have developed or are developing a close relationship with CBOT prices based on: 1) the fact that CZCE was established a decade ago with the help from CBOT so that many institutional features of the two markets are the same, and 2) some preliminary statistical calculations reveal the prices from the two markets have a strong association (CZCE Report, 2001).

Although China is becoming more integrated into the world economy and its trade policies are more liberalized after its WTO accession, the relationship between CZCE and CBOT has not yet shown a clear pattern. Although there are reasons to expect wheat futures prices in the two markets to move together closer, there are also reasons to expect otherwise. Such reasons

include the fact that physical wheat trading volume between the two countries is still a small proportion compared to the domestic production and consumption levels, regulatory and institutional barriers still interfere with China's market development, and futures traders involved in both markets are not many yet. Based on our data on wheat futures prices around the WTO accession, the cross-market effects are not yet evident in terms of cointegration in the mean level. This implies the long-run equilibrium relationship that binds the price movements in the CZCE and CBOT do not exist. However, we still find transmission in the contract switching effect and volatility, depending on model specification, between the two markets. Although the linkage is not strong, it implies an asymmetric pattern. That is, the CBOT has a stronger influence on the CZCE than the CZCE has on the CBOT. This implies the CBOT plays a leading role in market interaction, while CZCE is more like a follower. Such an interaction discloses the existence of a weak connection between China's and the US's wheat futures market on one hand, but on the other hand. On the other hand, the asymmetric property of the relationship indicates China's wheat futures market is not strong enough to influence the world market but may be influenced by the world market.

## **V. Conclusion**

After more than ten years of development, the CZCE has become the biggest commodity futures market in China. The CZCE wheat futures trading has important effects on wheat prices in China's agricultural price system. This paper makes an effort to investigate the wheat futures price behavior in the CZCE, and more importantly to assess the integration of the CZCE into the world market. The CBOT is used to represent the world market. Previous studies on the market integration of China's wheat futures market, such as the CZCE report (2001),

focused on a pairwise correlation analysis of prices and assumed constant price volatility. In this paper, we consider the cointegration relationship and model price behavior of two wheat futures markets simultaneously based on time variant conditional variances, using an ARCH/GARCH procedure.

Model fitting shows that both CZCE and CBOT price can be best modeled by ARCH(1)/GARCH(1,1) processes. These results are consistent with the empirical studies of high frequency commodity prices (Myers, 1994; Poon and Granger, 2003). Bivariate analysis of CZCE and CBOT prices shows the two series are not cointegrated. The existing cross-equation effects, or the interrelationships, between the two markets are significant but weak, and asymmetric assuming a normal distribution. The CBOT plays a leading role in the interactions and the CZCE is more like a follower. This result reveals that the two prices evolve in a similar way and coincide to one another through the season, but there is not strong evidence of information flow from one market to the other. However, under the t-distribution, no significant evidence can be found of any interaction between the two markets. This means the relationship between the two markets has not shown a clear pattern.

Results indicate that the price in China's wheat futures behaves in the similar way as the price in the representative world market. This is a good sign suggesting that the Chinese agricultural commodity market is performing in line with world markets. On the other hand, the short memory feature of the CZCE compared to the CBOT indicates that the CZCE is more volatile and chaotic. This suggests that either the Chinese traders are less mature or the Chinese food market environment is less stable. The one-way impact from CBOT to CZCE and the weak relation between the two markets indicate that China's wheat market is not fully integrated with the world market at this point.



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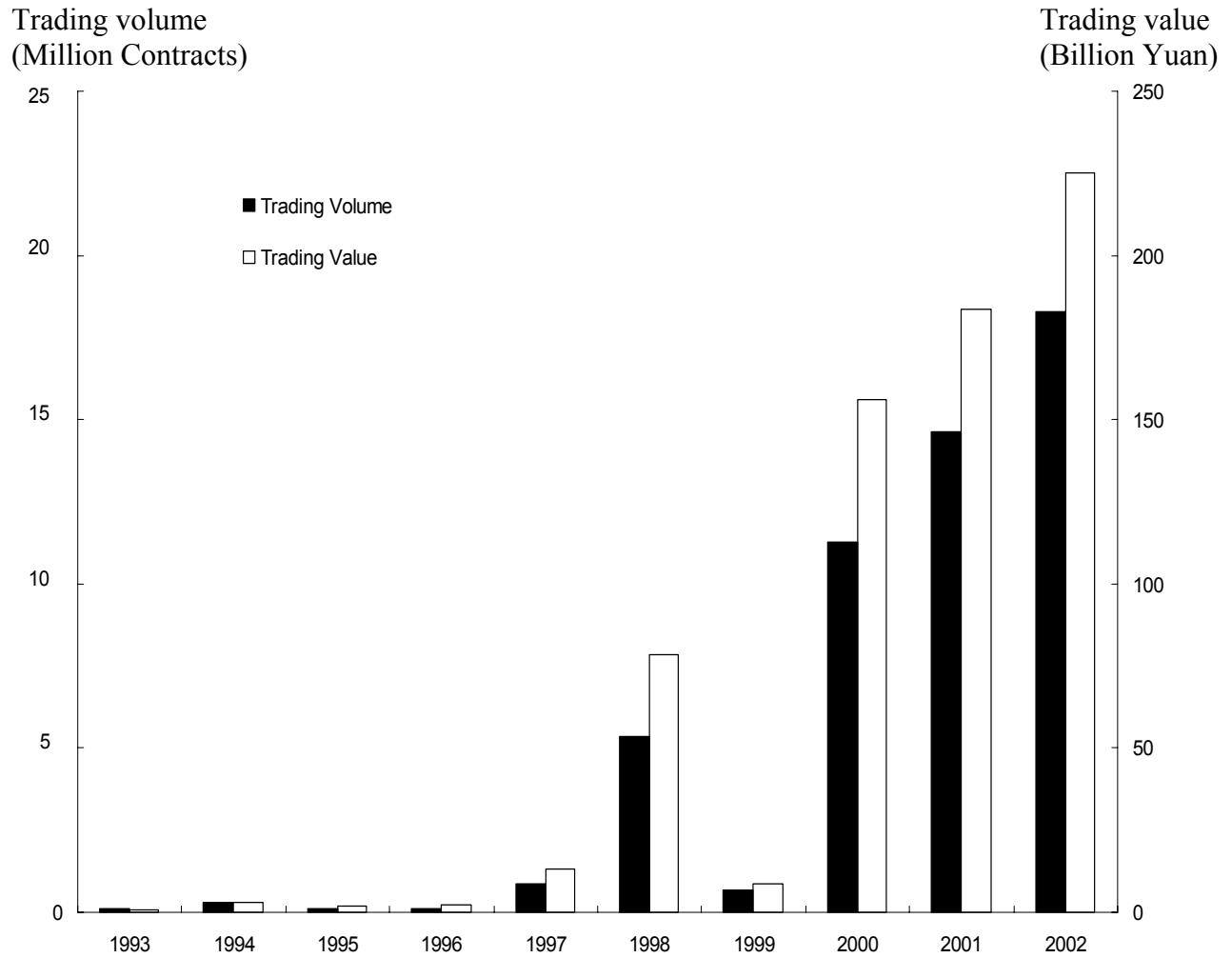
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**Figure 4.1. Annual Wheat Futures Trading for CZCE 1993-2002**

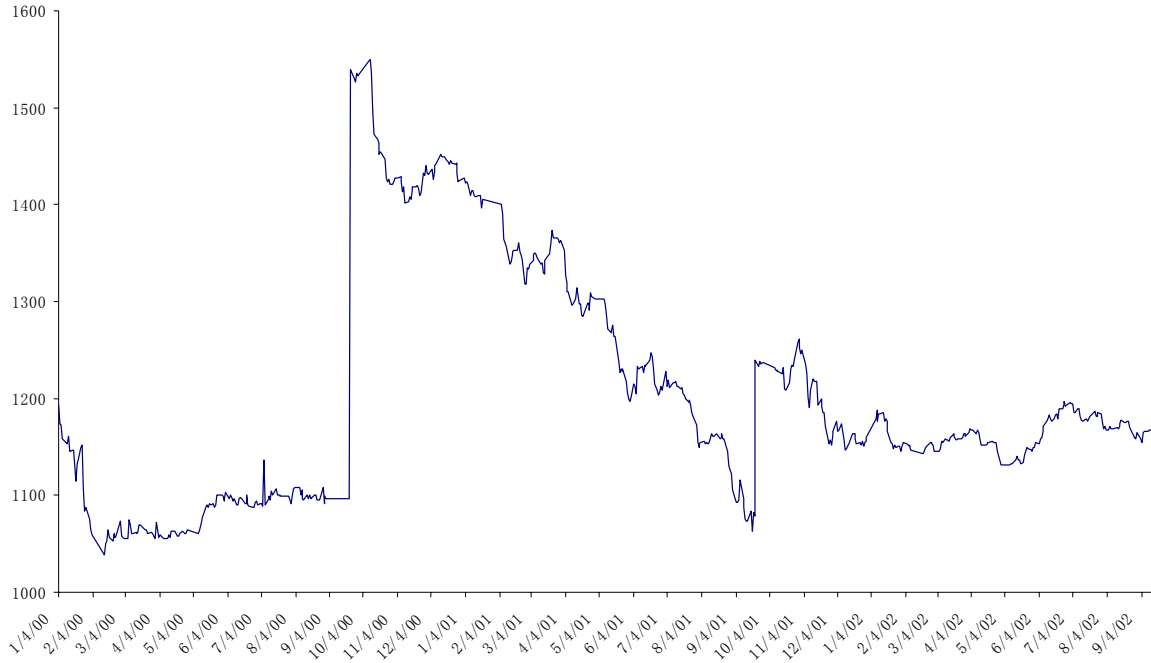


Data source: CZCE 2002 Annals (<http://www.czce.com.cn/home/annals.asp>)

**Figure 4.2. CZCE and CBOT Wheat Futures Price for September Contract**

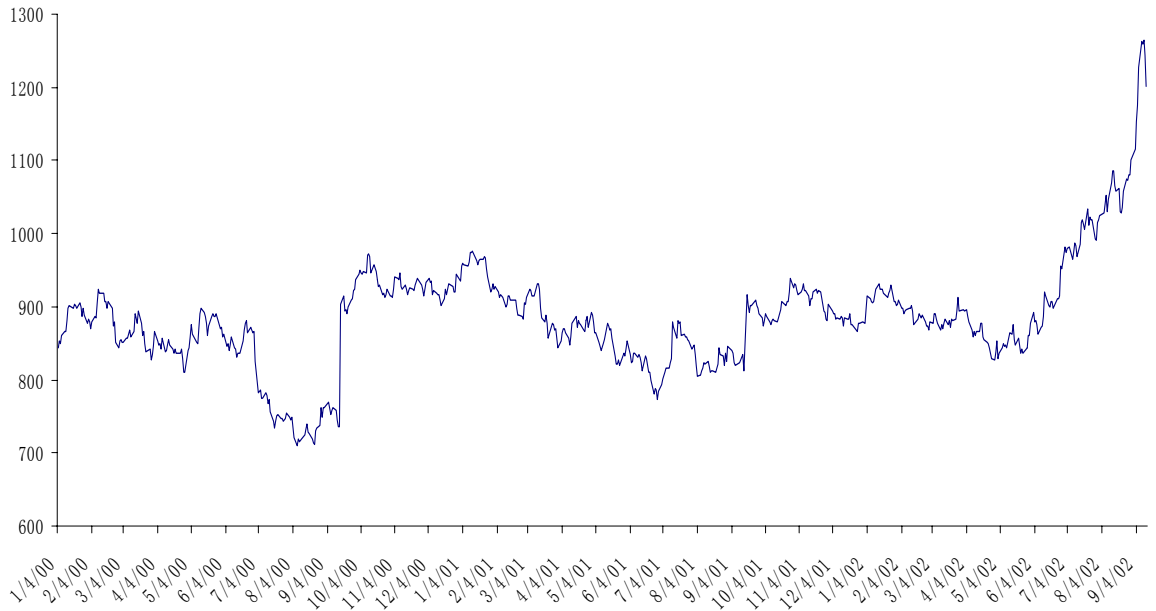
**CZCE Daily Settlement Prices**

Unit: Yuan/Ton



**CBOT Daily Settlement Prices**

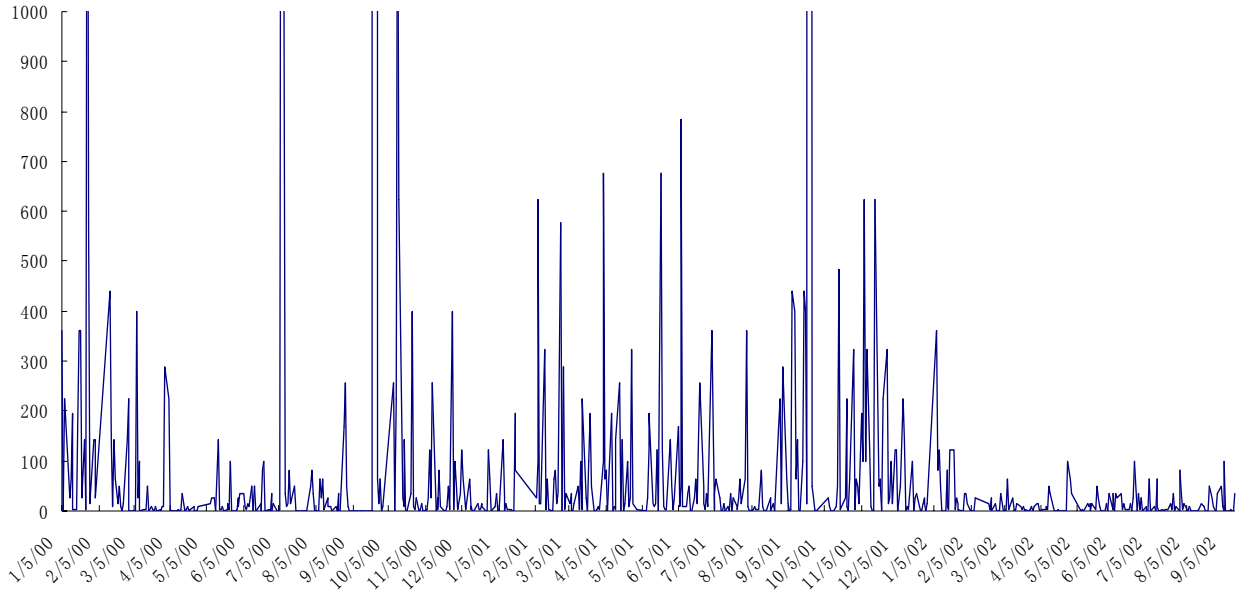
Unit: Yuan/Ton



**Figure 4.3. Squared First Difference of CZCE and CBOT Wheat Futures Prices**

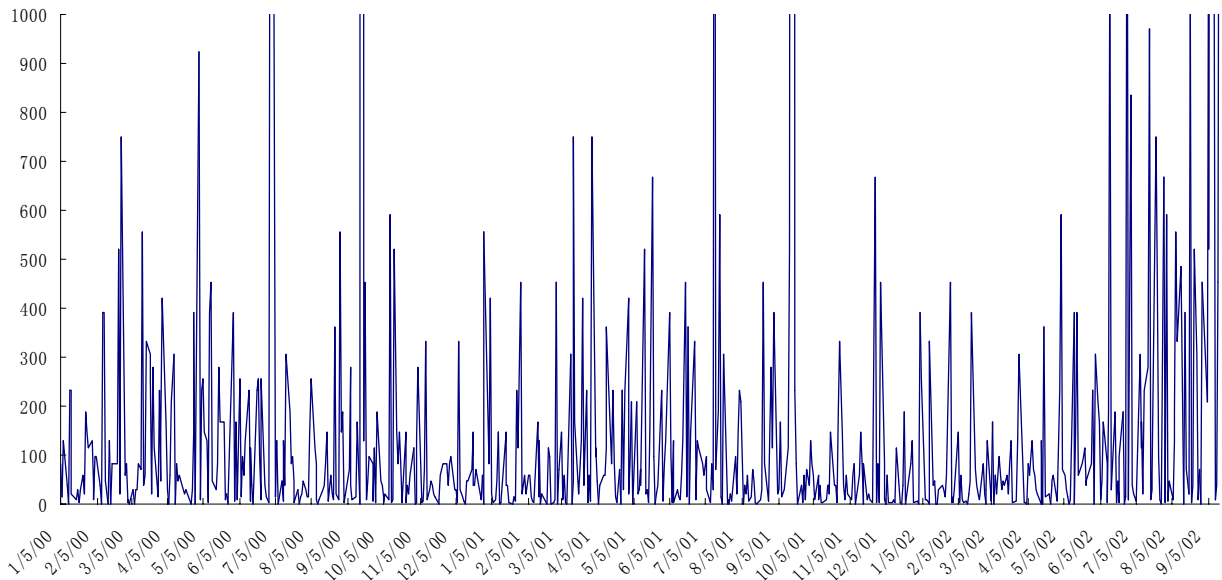
**CZCE September Contract**

Unit: Yuan<sup>2</sup>/Ton<sup>2</sup>



**CBOT September Contract**

Unit: Yuan<sup>2</sup>/Ton<sup>2</sup>



Note: Since some squared first difference prices are very high compared to the rest, especially those at switching points, we cut off some of the spikes to fit them into the plot.

**Table 4.1. Estimates of Selected Univariate ARCH/GARCH models**

Model	$\varepsilon_t   \Omega_{t-1} \sim normal$		$\varepsilon_t   \Omega_{t-1} \sim student\ t$	
	CZCE - ARCH(1)	CBOT - ARCH(1)	CZCE - GARCH(1,1)	CBOT - ARCH(1)
$\beta_0$	-0.77 (0.60)	0.54 (0.62)	-0.22(0.20)	-0.13 (0.40)
$\delta$	298.6* (0.76)	-18.26 (70.27)	322.43* (18.08)	-19.11 (37.80)
$\omega$	110.96* (0.89)	168.45* (2.41)	2.54* (1.11)	130.33* (12.93)
$\alpha_1$	0.05* (0.02)	0.10* (0.02)	0.04* (0.02)	0.12* (0.06)
$\gamma_1$	--	--	0.94*(0.02)	--
AIC	4974.8	5449.5	4332.9	4359.7
BIC	4992.7	5467.6	5215.0	5237.6

Note: 1. “\*” denotes significance at the 5% level.

2. Standard errors are listed in parentheses.

3. The estimated GARCH(1,1) model is defined as:

$$\Delta P_t = \beta_0 + \delta SD_t + \varepsilon_t, \quad \varepsilon_t | \Omega_{t-1} \sim N(0, h_t),$$

where  $h_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \gamma_1 h_{t-1}$  with  $P_t$  denoting price at time  $t$ .

The ARCH(1) is obtained when  $\gamma_1$  is set to zero in the above specification



**Table 4.2. Nonsynchronous Trading Effect Estimation**

Coefficient Estimates	CBOT	CZCE
$\alpha$	0.04 (0.16)	-1.01 (0.46)
$\beta_0$	<b>0.0044 (0.01)</b>	0.05 (0.10)
$\beta_1$	0.01 (0.01)	<b>0.05 (0.10)</b>
$\delta$	44.69* (2.81)	302.91* (8.06)

Note:1. “\*” denotes significance at the 5% level, and standard errors are listed in parentheses.

2. The regression models to be estimated are defined as:

$$\text{For CBOT: } \Delta P_t^B = \alpha + \beta_0 \Delta P_t^Z + \beta_1 \Delta P_{t-1}^Z + \delta SD_t^B + \varepsilon_t$$

$$\text{For CZCE: } \Delta P_t^Z = \alpha + \beta_0 \Delta P_t^B + \beta_1 \Delta P_{t-1}^B + \delta SD_t^Z + \varepsilon_t$$

**Table 4.3. Estimates of Selected Multivariate ARCH/GARCH models**

Model	BEKK Modeling		CCC Modeling		DVEC Modeling	
	ARCH(1) - N	ARCH(1) - t	GARCH(1,1) - N	GARCH(1,1) - t	GARCH(1,1) - N	GARCH(1,1) - t
$\mu^B$	0.009 (0.49)	-0.002 (0.48)	-0.16 (0.48)	-0.21 (0.47)	-0.26 (0.48)	-0.20 (0.47)
$\mu^Z$	-0.97* (0.63)	-0.48* (0.31)	-0.15 (0.43)	-0.15 (0.26)	-0.13 (0.40)	-0.16 (0.27)
$\Lambda_{BB}$	141.80* (11.49)	138.20* (6.76)	135.30* (4.69)	133.98* (3.44)	129.60* (6.92)	133.77* (3.49)
$\Lambda_{7B}$	6.05 (56.13)	3.48 (13.75)	48.28* (1.96)	-1.09 (10.50)	-39.21* (2.10)	-0.81 (10.65)
$\Lambda_{BZ}$	3.21 (150.47)	1.74 (548.57)	3.98 (169.18)	7.28 (119.49)	3.58 (4.37)	8.53 (63.28)
$\Lambda_{7Z}$	280.89* (5.66)	303.09* (22.73)	321.02* (20.25)	437.80* (7.95)	360.83* (2.97)	437.92* (3.65)
$\omega_u$	11.34* (0.28)	11.40* (0.33)	2.13* (1.64)	1.99 (1.81)	1.98 (1.59)	1.95 (1.83)
$\omega_{uv}$	0.07 (0.64)	-0.17 (0.35)	--	--	0.02 (0.08)	-2.29 (6.88)
$\omega_v$	10.83* (0.08)	6.72* (0.20)	5.64* (1.34)	5.13* (0.90)	5.08* (1.19)	5.15* (0.91)
$A_{uu}$	0.34* (0.05)	0.21* (0.06)	0.03* (0.009)	0.03* (0.010)	0.03* (0.009)	0.03* (0.010)
$A_{vu}$	-0.04 (0.14)	-0.01 (0.05)	--	--	-0.02* (0.01)	-0.007 (0.03)
$A_{uv}$	0.09 (0.10)	0.002 (0.08)	--	--	--	--
$A_{vv}$	0.20* (0.05)	0.46* (0.05)	0.22* (0.04)	0.24* (0.04)	0.24* (0.04)	0.24* (0.04)
$\Gamma_{uu}$	--	--	0.96* (0.02)	0.96* (0.02)	0.96* (0.02)	0.96* (0.02)
$\Gamma_{vu}$	--	--	--	--	0.99* (0.009)	-0.92 (0.25)
$\Gamma_{vv}$	--	--	0.79* (0.04)	0.69* (0.03)	0.78* (0.03)	0.69* (0.03)
$\rho_{uv}$	--	--	-0.04 (0.05)	-0.02 (0.05)	--	--
AIC	9687.1	9398.4	9438.0	9293.4	9406.1	9299.2
BIC	9744.8	9460.5	9491.2	9351.0	9472.6	9370.2

Note: 1. “\*” denotes significant at 5% level, and .standard errors are listed in the parentheses.

2. The estimated ARCH(1) model in BEKK form is defined as:

$$\begin{pmatrix} \Delta P_t^B \\ \Delta P_t^Z \end{pmatrix} = \begin{pmatrix} \mu^B \\ \mu^Z \end{pmatrix} + \Lambda \begin{pmatrix} SD_t^B \\ SD_t^Z \end{pmatrix} + \begin{pmatrix} u_t \\ v_t \end{pmatrix}, \text{ where } \begin{pmatrix} u_t \\ v_t \end{pmatrix} \Big| \Omega_{t-1} \sim \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{u,t}^2 & \\ & \sigma_{v,t}^2 \end{pmatrix}, \begin{pmatrix} \sigma_{u,t}^2 & \\ \sigma_{uv,t} & \sigma_{v,t}^2 \end{pmatrix} = \begin{pmatrix} \omega_u & \\ \omega_{uv} & \omega_v \end{pmatrix} + A \begin{pmatrix} u_{t-1}^2 & \\ u_{t-1}v_{t-1} & v_{t-1}^2 \end{pmatrix} A'$$

the GARCH(1,1) model in CCC form has the variance equation of the form:

$$\sigma_{i,t}^2 = \omega_i + A_{ii}i_{t-1}^2 + \Gamma_{ii}\sigma_{i,t-1}^2, i = u, v; \sigma_{ij,t} = \rho_{ij}\sqrt{\sigma_{i,t}^2\sigma_{j,t}^2}, i, j = u, v, \text{ and } i \neq j,$$

and the GARCH(1,1) model in DVEC form has a different variance equation:

$$\begin{pmatrix} \sigma_{u,t}^2 & \\ \sigma_{uv,t} & \sigma_{v,t}^2 \end{pmatrix} = \begin{pmatrix} \omega_u & \\ \omega_{uv} & \omega_v \end{pmatrix} + A \odot \begin{pmatrix} u_{t-1}^2 & \\ u_{t-1}v_{t-1} & v_{t-1}^2 \end{pmatrix} + \Gamma \odot \begin{pmatrix} \sigma_{u,t-1}^2 & \\ \sigma_{uv,t-1} & \sigma_{v,t-1}^2 \end{pmatrix}.$$

The superscript B denotes CBOT and the superscript Z denotes CZCE.

**Table 4.4. Within and Cross Market Effects of Bivariate BEKK-ARCH(1)**

	$\sigma_{u,t}^2$	$\sigma_{uv,t}$	$\sigma_{v,t}^2$
<i>H<sub>t</sub>   Ω<sub>t-1</sub> ~ normal</i>			
$u_{t-1}^2$	0.1132	-0.0126	0.0014
$u_{t-1}v_{t-1}$	0.0579	0.0639	-0.0149
$v_{t-1}^2$	0.0074	0.0172	0.0398
<i>H<sub>t</sub>   Ω<sub>t-1</sub> ~ student t</i>			
$u_{t-1}^2$	0.0453	-0.0022	0.0001
$u_{t-1}v_{t-1}$	0.0007	0.0973	-0.0096
$v_{t-1}^2$	0.29E-5	0.0008	0.2091

Note: 1. The reported values are calculated as in Appendix B.2.

2. The estimated ARCH(1) model in BEKK form is defined as:

$$\begin{pmatrix} \Delta P_t^B \\ \Delta P_t^Z \end{pmatrix} = \begin{pmatrix} \mu^B \\ \mu^Z \end{pmatrix} + \Lambda \begin{pmatrix} SD_t^B \\ SD_t^Z \end{pmatrix} + \begin{pmatrix} u_t \\ v_t \end{pmatrix}, \text{ where } \begin{pmatrix} u_t \\ v_t \end{pmatrix} \Big| \Omega_{t-1} \sim \left( \begin{pmatrix} 0 \\ 0 \end{pmatrix}, \begin{pmatrix} \sigma_{u,t}^2 & \\ & \sigma_{v,t}^2 \end{pmatrix} \right),$$

$$\begin{pmatrix} \sigma_{u,t}^2 & \\ \sigma_{uv,t} & \sigma_{v,t}^2 \end{pmatrix} = \begin{pmatrix} \omega_u & \\ \omega_{uv} & \omega_v \end{pmatrix} + A \begin{pmatrix} u_{t-1}^2 & \\ u_{t-1}v_{t-1} & v_{t-1}^2 \end{pmatrix} A'$$

**APPENDIX A: DETAILED IMPACT ANALYSIS RESULTS FOR CHAPTER 3**

**A.1. Detailed Results for the Sensitivity of Optimal Hedge Ratios in Response to  
Risk Aversion ( $\alpha$ )**

$\alpha$	Year1	Year2	Year3	Year4	Year5
-5	-0.3371	-0.3096	-0.2683	-0.2149	-0.1062
-4	-0.3414	-0.3198	-0.2849	-0.2374	-0.1236
-3	0.3420	0.3282	0.3008	0.2619	0.1465
-2	0.3357	0.3332	0.3148	0.2872	0.1770
-1	0.3132	0.3301	0.3238	0.3107	0.2162
-0.8	0.3045	0.3276	0.3242	0.3148	0.2250
-0.6	0.2934	0.3236	0.3240	0.3182	0.2339
-0.4	0.2789	0.3183	0.3227	0.3212	0.2430
-0.2	0.2598	0.3103	0.3199	0.3231	0.2521
0.2	0.1958	0.2814	0.3056	0.3213	0.2684
0.4	0.1368	0.2533	0.2895	0.3140	0.2739
0.6	0.0365	0.2019	0.2573	0.2952	0.2737

**Appendix A.2. Detailed Results for the Sensitivity of Optimal Hedge Ratios in Response to  
Time Preference ( $\beta$ )**

$\beta$	Year1	Year2	Year3	Year4	Year5
0.05	-0.3157	-0.3098	-0.1399	-0.0017	-0.0083
0.1	-0.3170	-0.3075	-0.2846	-0.1994	0.0130
0.15	0.3190	0.3110	0.2996	0.2983	0.2547
0.2	0.3204	0.3142	0.3033	0.3017	0.2551
0.3	0.3213	0.3188	0.3094	0.3072	0.2551
0.4	0.3194	0.3216	0.3138	0.3117	0.2551
0.5	0.3141	0.3223	0.3168	0.3151	0.2551
0.6	0.3048	0.3210	0.3185	0.3179	0.2551
0.7	0.2910	0.3179	0.3193	0.3202	0.2551
0.8	0.2725	0.3129	0.3191	0.3220	0.2551
0.9	0.2491	0.3061	0.3183	0.3235	0.2551

**Appendix A.3. Detailed Results for the Sensitivity of Optimal Hedge Ratios in Response to  
Intertemporal Substitutability ( $\rho$ )**

$\rho$	Year1	Year2	Year3	Year4	Year5
-5	0.2905	0.2754	0.2630	0.2778	0.2567
-4	0.2912	0.2754	0.2632	0.2766	0.2555
-3	0.2925	0.2756	0.2639	0.2750	0.2551
-2	0.2960	0.2779	0.2657	0.2739	0.2552
-1	0.3038	0.2851	0.2720	0.2756	0.2551
-0.8	0.3059	0.2875	0.2742	0.2767	0.2551
-0.6	0.3079	0.2904	0.2769	0.2784	0.2551
-0.4	0.3098	0.2936	0.2801	0.2805	0.2551
-0.2	0.3115	0.2971	0.2838	0.2834	0.2551
0.2	0.3115	0.3043	0.2930	0.2917	0.2551
0.4	0.3084	0.3074	0.2985	0.2976	0.2551
0.6	0.3011	0.3097	0.3047	0.3050	0.2551
0.8	0.2818	0.3098	0.3118	0.3145	0.2551

**Appendix A.4. Detailed Results for the Sensitivity of Optimal Hedge Ratios in Response to Transaction Cost Level (TC)**

	TC	Year1	Year2	Year3	Year4	Year5	Year1	Year2	Year3	Year4	Year5
109		With CCP					Without CCP				
	0	0.4221	0.3862	0.3654	0.3522	0.2678	0.6119	0.5405	0.4976	0.4784	0.3935
	0.001	0.4219	0.3860	0.3654	0.3523	0.2679	0.6118	0.5405	0.4974	0.4784	0.3935
	0.002	0.4215	0.3862	0.3654	0.3522	0.2678	0.6113	0.5405	0.4975	0.4780	0.3933
	0.003	0.4214	0.3861	0.3652	0.3522	0.2678	0.6113	0.5403	0.4976	0.4781	0.3934
	0.004	0.4216	0.3858	0.3655	0.3521	0.2678	0.6111	0.5402	0.4975	0.4781	0.3934
	0.005	0.4214	0.3861	0.3652	0.3521	0.2678	0.6111	0.5401	0.4972	0.4782	0.3935
	0.006	0.4211	0.3859	0.3652	0.3521	0.2677	0.6105	0.5401	0.4973	0.4781	0.3934
	0.007	0.4213	0.3859	0.3652	0.3521	0.2677	0.6104	0.5399	0.4974	0.4782	0.3934
	0.008	0.4209	0.3858	0.3651	0.3520	0.2677	0.6105	0.5400	0.4973	0.4780	0.3933
	0.009	0.4210	0.3857	0.3650	0.3521	0.2677	0.6104	0.5399	0.4972	0.4780	0.3934
	0.01	0.4206	0.3857	0.3649	0.3520	0.2677	0.6098	0.5396	0.4971	0.4779	0.3933
	0.011	0.4203	0.3856	0.3651	0.3520	0.2677	0.6094	0.5397	0.4971	0.4779	0.3933
	0.012	0.4205	0.3855	0.3649	0.3519	0.2677	0.6097	0.5398	0.4971	0.4781	0.3934
	0.013	0.4202	0.3854	0.3649	0.3519	0.2677	0.6095	0.5396	0.4969	0.4781	0.3934
	0.014	0.4201	0.3855	0.3650	0.3519	0.2677	0.6092	0.5396	0.4971	0.4779	0.3933
	0.015	0.4199	0.3856	0.3648	0.3519	0.2677	0.6090	0.5397	0.4970	0.4778	0.3932
	0.016	0.4201	0.3851	0.3649	0.3518	0.2676	0.6086	0.5395	0.4969	0.4778	0.3933
	0.017	0.4200	0.3850	0.3648	0.3517	0.2676	0.6090	0.5391	0.4968	0.4778	0.3933
	0.018	0.4200	0.3850	0.3649	0.3518	0.2676	0.6084	0.5392	0.4968	0.4777	0.3932
0.019	0.4195	0.3851	0.3648	0.3518	0.2676	0.6086	0.5389	0.4967	0.4776	0.3932	
0.02	0.4196	0.3849	0.3648	0.3518	0.2676	0.6083	0.5391	0.4967	0.4778	0.3932	



**APPENDIX B: DETAILED MODEL FITTING RESULTS FOR CHAPTER 4**

### Appendix B.1. Univariate ARCH/GARCH Model Fitting Results

Model	AIC	BIC	Insignificant Coefficients
$\varepsilon_t   \Omega_{t-1} \sim normal$			
<b>CZCE: ARCH(1)</b>	<b>4974.8</b>	<b>4992.7</b>	$\beta_0$
<b>CBOT: ARCH(1)</b>	<b>5449.5</b>	<b>5467.6</b>	$\beta_0, \delta$
ARCH(2)	5451.5	5474.1	$\beta_0, \delta, \alpha_2$
GARCH(1,1)	5452.9	5475.5	$\beta_0, \delta, \gamma_1$
$\varepsilon_t   \Omega_{t-1} \sim student\ t$			
<b>CZCE: GARCH(1,1)</b>	<b>4332.9</b>	<b>4359.7</b>	$\beta_0$
GARCH(1,2)	4331.8	4363.1	$\beta_0, \gamma_1$
<b>CBOT: ARCH(1)</b>	<b>5215.0</b>	<b>5237.6</b>	$\beta_0, \delta$
ARCH(2)	5214.8	5241.9	$\beta_0, \delta, \alpha_2$
GARCH(1,1)	5215.4	5242.5	$\beta_0, \delta, \gamma_1$

Note: 1. Significance is at 5%.

2. Models of other lower orders are not convergent.

3. The estimated GARCH(1,1) model is defined as:

$$\Delta P_t = \beta_0 + \delta SD_t + \varepsilon_t, \quad \varepsilon_t | \Omega_{t-1} \sim N(0, h_t),$$

where  $h_t = \omega + \alpha_1 \varepsilon_{t-1}^2 + \gamma_1 h_{t-1}$  with  $P_t$  denoting price at time t.

The ARCH(1) is obtained when  $\gamma_1$  is set to zero in the above specification.

**Appendix B.2. Derivation of Own and Cross Market Effects of Conditional Variances in a multivariate ARCH model (BEKK form)**

By the definition of BEKK-ARCH(1), the conditional error variance equation can be specified as:

$$\begin{pmatrix} \sigma_{u_t}^2 & \\ \sigma_{uv_t} & \sigma_{v_t}^2 \end{pmatrix} = \begin{pmatrix} \omega_u & \\ \omega_{uv} & \omega_v \end{pmatrix} + \begin{pmatrix} A_{uu} & A_{uv} \\ A_{vu} & A_{vv} \end{pmatrix} \begin{pmatrix} u_{t-1}^2 & \\ u_{t-1}v_{t-1} & v_{t-1}^2 \end{pmatrix} \begin{pmatrix} A_{uu} & A_{uv} \\ A_{vu} & A_{vv} \end{pmatrix}' \\ = \begin{pmatrix} \omega_u & \\ \omega_{uv} & \omega_v \end{pmatrix} + \begin{pmatrix} A_{uu}^2 u_{t-1}^2 + 2A_{uv}A_{uu}v_{t-1}u_{t-1} + A_{uv}^2 v_{t-1}^2 & \\ A_{uu}A_{vu}u_{t-1}^2 + (A_{uu}A_{vv} + A_{uv}A_{vu})u_{t-1}v_{t-1} + A_{uv}A_{vv}v_{t-1}^2 & A_{vu}^2 u_{t-1}^2 + 2A_{vu}A_{vv}v_{t-1}u_{t-1} + A_{vv}^2 v_{t-1}^2 \end{pmatrix}$$

To obtain the own and cross market effects from this specification, we take partial derivative of each dependent variable with respect to the respective explanatory variables to get the needed effects.

$$\text{Own market effects: } \frac{\partial \sigma_{u_t}^2}{\partial u_{t-1}^2} = A_{uu}^2, \quad \frac{\partial \sigma_{v_t}^2}{\partial v_{t-1}^2} = A_{vv}^2$$

$$\text{Cross market effects: } \frac{\partial \sigma_{u_t}^2}{\partial v_{t-1}^2} = A_{uv}^2, \quad \frac{\partial \sigma_{v_t}^2}{\partial u_{t-1}^2} = A_{vu}^2$$

$$\text{Other effects: } \frac{\partial \sigma_{u_t}^2}{\partial u_{t-1}v_{t-1}} = 2A_{uv}A_{uu}, \quad \frac{\partial \sigma_{v_t}^2}{\partial u_{t-1}v_{t-1}} = 2A_{vu}A_{vv}$$

$$\text{Covariance effects: } \frac{\partial \sigma_{uv_t}}{\partial u_{t-1}^2} = A_{uu}A_{vu}, \quad \frac{\partial \sigma_{uv_t}}{\partial v_{t-1}^2} = A_{uv}A_{vv}, \quad \frac{\partial \sigma_{uv_t}}{\partial u_{t-1}v_{t-1}} = A_{uu}A_{vv} + A_{uv}A_{vu}$$

**APPENDIX C: COMPUTER PROGRAMS FOR CHAPTER 2**

## Appendix C.1. Stochastic Trend Model Estimation (in GAUSS)

```
new;
cls;

print;
print " stochastic trend model (normal): Kalman filter Model
      -- Whitman County Wheat All Crop Total

      Y(t) = U(t) + eps(t)
      U(t) = U(t-1) + Beta(t-1) + eta(t)
      Beta(t) = Beta(t-1) + zeta(t)

      alpha(t) = {U(t), Beta(t)}

      ©2005 Wen Du. All rights reserved.

";

/*****
Part I: estimation
*****/

print;
print "Optimization of stochastic trend for the simulation of wheat production";
print;

load yield[65,1] = D:\arec\whitman_wyld39to03.txt;

/*initialize the parameters required for the optimization*/

/*case 1: assume normal distribution of epsilon*/
x0 = {30,1,11,0.5,0.5}; /*x0 = {u0, b0, sig_eps, sig_eta, sig_zeta}*/

/*case 2: relax normality assumption - inverse hyperbolic transformation*/
x0 = {30,1,30,3,0.5,0.1,0.5}; /*x0 = {u0, b0, sig_eps^2, sig_eta, sig_zeta, theta, delta}*/

/*initialize the alpha_t and p_t used for simulation later*/
a_t1 = {0,0};
a_t2 = {0,0};
P_t1 = zeros(2,2);
P_t2 = zeros(2,2);

/*optimization using both sqpSolve and Qnewton algorithms*/
```

```

sqpsolveset;
{bsqp, L1, lagr, ret} = sqpsolve( &fct, x0);

{bqnew, L2,gradient, ret} = qnewton( &fct, x0);

/*calculate covariance matrix of estimated parameters*/
hsqp = hessp(&fct, bsqp);
hqnew = hessp(&fct, bqnew);

/*calculate standard error of estimated parameters*/
stdsqp = sqrt(diag(invdpd(hsqp)));
stdqnew = sqrt(diag(invdpd(hqnew)));

/*calculate t-value and p-value of estimated parameters*/
tsqp = bsqp./stdsqp;
tqnew = bqnew./stdqnew;

psqp = 2 * cdfnc(abs(tsqp));
pqnew = 2 * cdfnc(abs(tqnew));

/**ouput**/

print;
print "      Optimization Results by sqpSolve";
print;
print "  initial values  estimates  standard error  t-value  p-value";
print x0~bsqp~stdsqp~tsqp~psqp;
print;
print;
print "      Optimization Results by Qnewton";
print;
print "  initial values  estimates  standard error  t-value  p-value";
print x0~bqnew~stdqnew~tqnew~pqnew;
print;
print;

/*****
Part II: computation of simulation starting points
*****/

/*simulate the yield data for the next X years using the esimated values*/

```

```

print;
print " Length of the historical yield, N = " rows(yield) "years";
print;
print "starting point alpha_N = (" a_t1[1] ", " a_t1[2] ")";
print;
print "starting point alpha_{N+1|N} = (" a_t2[1] ", " a_t2[2] ")";
print;
print "starting point   p_{N+1|N} = " P_t2[1,1] P_t2[1,2];
print "                " P_t2[2,1] P_t2[2,2];
print;

end;

proc fct(x);          /*define and calculate the log likelihood*/
  local z, T, Q, N, i, eps, at, Pt, at1, Pt1, at2, Pt2,
        f, L,w,e,theta, delta, col1, col2;

  /*initialize variables for the iteration*/
  z = {1 0};
  T[2,2] = {1 1, 0 1};
  Q = (x[4]^2~0)|(0~x[5]^2);

  N = rows(yield); /*number of observations*/

  at = x[1:2];
  Pt = {10 0, 0 1};

  L = 0;

  /*recursive iteration for calculating the log likelihood*/

  /* case 1: normally distributed error terms*/

  for i (1, N, 1);
    at1 = at;
    pt1 = pt;
    at2 = T * at1;
    Pt2 = T * Pt1 * T' + Q;
    eps = yield[i] - z * at2;
    f = z * Pt2 * z' + x[3]^2;
    at = at2 + Pt2 * z' * eps / f;
    Pt = Pt2 - Pt2 * z'z * Pt2 / f;
    L = L - .5 * (ln(abs(f)) + (eps ^ 2) / f);
  endfor;

```

```

/*case 2: inverse hyperbolic sine transformation on the error terms*/
/*
theta = x[6];
delta = x[7];

for i (1, N, 1);
    at1 = at;
    Pt1 = Pt;
    at2 = T * at1;
    Pt2 = T * Pt1 * T' + Q;
    eps = yield[i] - z * at2;
    w = (ln(theta * eps + sqrt((theta * eps) ^ 2 + 1))) / theta;
    e = w - delta;
    f = z * Pt2 * z' + x[3];
    at = at2 + Pt2 * z' * e / f;
    Pt = Pt2 - Pt2 * z'z * Pt2 / f;
    L = L - .5 * (ln(abs(f)) + (e ^ 2) / f + ln((theta * eps) ^ 2 + 1));
endfor;
*/
a_t1 = at; /*at=alpha(65) at the end of the iteration*/
P_t1 = pt; /*Pt=P(65) at the end of the iteration*/
a_t2 = T * a_t1; /*a_t2=alpha(66|65)*/
P_t2 = T * P_t1 * T' + Q; /*P_t2=P(66|65)*/

retp(-L);
endp;

```



## Appendix C.2. Stochastic Trend Model Simulation (in GAUSS)

```
new;
cls;

print;
print;
print
"Simulation of Price data for GEU model -- Portland Wheat Cash Prices Annual and
  CBOT Sept Wheat Futures Prices Annual (correlation adjusted)

      ---- ©2005 Wen Du. All rights reserved."

Based on Stochastic trend model estimation under Normality, 1973-2003

Initial values are obtained from the estimation, where

for Portland Cash Prices:   alpha(31)={393.64974, -3.9161528}
                           sigsq_r_eps = 732.14732 or sig_eps = 27.05822093
                           sig_eta = 62.242636
                           sig_zeta = 0.00041566489

for CBOT futures Prices:   alpha(31)={358.5, -3.3998929}
                           sig_eps = 0.012782108
                           sig_eta = 68.904407
                           sig_zeta = 0.00052417892

Correlation coefficients: 0.871 for eps, eta, and zeta; 0.913 for original prices

                           rho= 0.871

";
print;
print
"*****";
print "*"      Based on the basic model, simulate wheat cash price data for next N years      *";
print
"*****";
print;

N = 5; /*number of simulated years ahead*/
M = 2050; /*number of sampling for each year*/

ro = 0.871; /*correlation coefficient*/
```

```

r_zeta = 0.00052417892 / 0.00041566489; /*ratio of sig_zeta: (wf/wc)*/
r_eta = 68.904407 / 62.242636; /*ratio of sig_eta: (wf/wc)*/
r_eps = 0.012782108 / 27.05822093; /*ratio of sig_epsilon: (wf/wc)*/

/* wheat Cash prices */

beta_wc = zeros(M,N);
miu_wc = zeros(M,N);
zeta_wc = zeros(M,N);
eta_wc = zeros(M,N);

eps_wc = zeros(M,N);
wcpri = zeros(M,N);

/* wheat Futures prices */

beta_wf = zeros(M,N);
miu_wf = zeros(M,N);
zeta_wf = zeros(M,N);
eta_wf = zeros(M,N);

eps_wf = zeros(M,N);
wfpri = zeros(M,N);

/** wheat futures prices, correlation adjusted **/
beta_wf_adj = zeros(M,N);
miu_wf_adj = zeros(M,N);
zeta_wf_adj = zeros(M,N);
eta_wf_adj = zeros(M,N);

eps_wf_adj = zeros(M,N);
wfpri_adj = zeros(M,N);

/*assign estimated values of {u, b} at t=31 for the recursive simulation starting at t=32*/

miu0_wc = 393.6497; /*from Cash price estimation, alpha(31)[,1]*/
beta0_wc = -3.9162; /*from Cash price estimation, alpha(31)[,2]*/

miu0_wf = 358.5; /*from Futures price estimation, alpha(31)[,1]*/
beta0_wf = -3.3999; /*from Futures price estimation, alpha(31)[,2]*/

/*calculate first year's Cash price simulation, based on historical estimated {miu(t),beta(t)} at
t=32*/

```

```

zeta_wc[:,1] = 0 * rndn(M,1);
beta_wc[:,1] = beta0_wc + zeta_wc[:,1];

eta_wc[:,1] = 62.2426 * rndn(M,1);
miu_wc[:,1] = miu0_wc + beta0_wc + eta_wc[:,1];

eps_wc[:,1] = 27.0582 * rndn(M,1);
wcpri[:,1] = miu_wc[:,1] + eps_wc[:,1];

print "var(simu_eps_wc)=" stdc(eps_wc)^2;
print "sample mean of var(simu_eps_wc)=" meanc(stdc(eps_wc)^2);

/*simulate 2nd till 5th year's of yield, based on first year's simulation*/
for t (2, N, 1);

    zeta_wc[:,t] = 0 * rndn(M,1);
    beta_wc[:,t] = beta_wc[:,t-1] + zeta_wc[:,t];
    eta_wc[:,t] = 62.2426 * rndn(M,1);
    miu_wc[:,t] = miu_wc[:,t-1] + beta_wc[:,t-1] + eta_wc[:,t];

    eps_wc[:,t] = 27.0582 * rndn(M,1);
    wcpri[:,t] = miu_wc[:,t] + eps_wc[:,t];

/*
print "var(simu_eps_wc)=" stdc(eps_wc)^2;*/

endfor;

/*
output file = D:\arec\output\wtsimu5year_wcpri_normalST.txt reset;
print;
print "          Simulated parameters";
print;
print "          miu" miu_wc;
print;
print "          beta" beta_wc;
print;
print "          eta" eta_wc;
print;
print "          zeta" zeta_wc;*/

print "          Simulated Yield for next 5 years";
print wcpri;
print;
print "    minPrice    meanPrice    StdDevPrice";
print minc(wcpri)~meanc(wcpri)~stdc(wcpri);

```

```

print;

bound_wc = minc(wcpri)./ meanc(wcpri);
print;
print "optimization bound_wc=" bound_wc;
print;
/*
output off;

library pgraph;

pqqwin "many";
graphset;

_pltype = {1 6 5};

_pmcolor = 7;
_pcolor = {3,2,13};

year = seqa(2002,1,N);

title("    Simulated Portland Sept Cash Prices Annual for next 5 years
        stochastic trend under normality" );
xy(year,meanc(wcpri));

title("    Simulated yield for next N years
        stochastic trend (5% and 95% quantiles)" );
quanlevel = {0.05,0.95};
quan = quantile(yield, quanlevel);
xy(year,meanc(wcpri)~quan);*/
/*
for j (1, N, 1);
    title("    Histogram of the Simulated yield for each year" );
    hist(wcpri[.j],30);
endfor;*/

print;
print
"*****";
print "*"    Based on the basic model, simulate wheat futures price data for next N years    *";
print
"*****";
print;

```

```
/*calculate first year's Futures price simulation, based on historical estimated {miu(t),beta(t)} at
t=33*/
```

```
zeta_wf[.,1] = 0.0005 * rndn(M,1);
beta_wf[.,1] = beta0_wf + zeta_wf[.,1];

eta_wf[.,1] = 68.9044 * rndn(M,1);
miu_wf[.,1] = miu0_wf + beta0_wf + eta_wf[.,1];

eps_wf[.,1] = 0.0128 * rndn(M,1);
wfpri[.,1] = miu_wf[.,1] + eps_wf[.,1];
```

```
print "var(simu_eps_wf)=" stdc(eps_wf)^2;
print "sample mean of var(simu_eps_wf)=" meanc(stdc(eps_wf)^2);
```

```
/**correlation adjustments to simulated Futures prices**/
```

```
zeta_wf_adj[.,1] = rho* (r_zeta) * zeta_wc[.,1] + sqrt(1 - ro^2) * zeta_wf[.,1];
beta_wf_adj[.,1] = beta0_wf + zeta_wf_adj[.,1];
```

```
eta_wf_adj[.,1] = rho* (r_eta) * eta_wc[.,1] + sqrt(1 - ro^2) * eta_wf[.,1];
miu_wf_adj[.,1] = miu0_wf + beta0_wf + eta_wf_adj[.,1];
```

```
eps_wf_adj[.,1] = rho* (r_eps) * eps_wc[.,1] + sqrt(1 - ro^2) * eps_wf[.,1];
wfpri_adj[.,1] = miu_wf_adj[.,1] + eps_wf_adj[.,1];
```

```
print "var(simu_eps_wf_adj)=" stdc(eps_wf_adj)^2;
print "sample mean of var(simu_eps_wf_adj)=" meanc(stdc(eps_wf_adj)^2);
```

```
/*simulate 2nd till 5th year's of yield, based on first year's simulation*/
for t (2, N, 1);
```

```
/*unadjusted simulated Futures prices*/
zeta_wf[.,t] = 0.0005 * rndn(M,1);
beta_wf[.,t] = beta_wf[.,t-1] + zeta_wf[.,t];
```

```
eta_wf[.,t] = 68.9044 * rndn(M,1);
miu_wf[.,t] = miu_wf[.,t-1] + beta_wf[.,t-1] + eta_wf[.,t];
```

```
eps_wf[.,t] = 0.0128 * rndn(M,1);
wfpri[.,t] = miu_wf[.,t] + eps_wf[.,t];
```

```
/*
print "var(simu_eps_wf)=" stdc(eps_wf)^2;*/
```

```
/*correlation adjusted simulated Futures price*/
zeta_wf_adj[.,t] = rho* (r_zeta) * zeta_wc[.,t] + sqrt(1 - ro^2) * zeta_wf[.,t];
```

```

beta_wf_adj[:,t] = beta_wf_adj[:,t-1] + zeta_wf_adj[:,t];

eta_wf_adj[:,t] = rho* (r_eta) * eta_wc[:,t] + sqrt(1 - ro^2) * eta_wf[:,t];
miu_wf_adj[:,t] = miu_wf_adj[:,t-1] + beta_wf_adj[:,t-1] + eta_wf_adj[:,t];

eps_wf_adj[:,t] = rho* (r_eps) * eps_wc[:,t] + sqrt(1 - ro^2) * eps_wf[:,t];
wfpri_adj[:,t] = miu_wf_adj[:,t] + eps_wf_adj[:,t];
/*
print "var(simu_eps_wf_adj)=" stdc(eps_wf_adj)^2;*/

endfor;
/*
output file = D:\arec\output\wtsimu5year_wfpri_normalST.txt reset;
print;
print "          Simulated parameters";
print;
print "          miu_wf" miu_wf;
print;
print "          beta_wf" beta_wf;
print;
print "          eta_wf" eta_wf;
print;
print "          zeta_wf" zeta_wf;
print;
print "          Simulated Yield for next 5 years";
print wfpri;
print;

print;
print "    minPrice    meanPrice    StdDevPrice";
print minc(wfpri)~meanc(wfpri)~stdc(wfpri);
print;

bound_wf = minc(wfpri)./ meanc(wfpri);
print;
print "optimization bound_wf = " bound_wf;
print;
*/

/*
print;
print "          miu_wf_adj" miu_wf_adj;
print;
print "          beta_wf_adj" beta_wf_adj;
print;
print "          eta_wf_adj" eta_wf_adj;

```

```

print;
print "                zeta_wf_adj" zeta_wf_adj;*/
print;
print "                Simulated Futures Price (correlation adjusted) for next 5 years";
print wfpri_adj;
print;

print;
print "    minPrice    meanPrice    StdDevPrice";
print minc(wfpri_adj)~meanc(wfpri_adj)~stdc(wfpri_adj);
print;

bound_wf_adj = minc(wfpri_adj)./ meanc(wfpri_adj);
print;
print "optimization bound_wf_adj = " bound_wf_adj;
print;

/*
library pgraph;

pqgwin "many";
graphset;

_pltype = {1 6 5};

_pmcolor = 7;
_pcolor = {3,2,13};

year = seqa(2002,1,N);

title("    Simulated Portland Sept Cash Prices Annual for next 5 years
        stochastic trend under normality" );
xy(year,meanc(wfpri));

title("    Simulated yield for next N years
        stochastic trend (5% and 95% quantiles)" );
quanlevel = {0.05,0.95};
quan = quantile(wfpri, quanlevel)';
xy(year,meanc(wfpri)~quan);*/
/*
for j (1, N, 1);
    title("    Histogram of the Simulated yield for each year" );
    hist(wfpri[:,j],30);
endfor;*/
end;

```

### Appendix C.3. Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer
```

$$\max U_t = \{(1-b)C_t^r + b[Et((U_{t+1})^a)]^{(r/a)}\}^{(1/r)}$$

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;
```

```
pqgwin "many";
```

```
/**set up parameters**/
```

```
M = 2000;
```

```
N = 6; /*number of years included in the optimization*/
```

```
T = N-1; /*number of recursion in the optimization*/
```

```
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
```

```
/**note: the terminal value (T+1) of generalized expected utility = 0*/
```

```
load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
```

```
load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;
```

```
/*
```

```
for q (1, T, 1);
```

```
    hist(yield[:,q],50);
```

```
endfor;*/
```

```
boundval_z = minc(yield)./meanc(yield);
```

```
print "boundval_z =" boundval_z;
```

```
print;
```

```
print meanc(yield)~minc(yield)~stdc(yield);
```

```
/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
```

```
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
```



```

load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

a = 0.5;
r = 0.5;/**/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);

```

```

IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - transport)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.1, -0.2, -0.1, -0.1, -0.1};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

X0 = X0_f*X0_i*/;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)'|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[:,i] = (mwf[i] + 0.45) * maxc( (CIcov * my[i] - yield[:,i]) ~ zeros(M,1) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[:,i]);
    CI[:,i] = IP[:,i] - CIload * MIP[i];
endfor;

```

```

sqpSolveSet;

{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);
/*
QnewtonSet;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);*/

/**ouput**/
print;
print "    alpha        beta        rho    transaction cost    production cost";
print a~b~r~trans~pc;
print;
print "Government Payment Programs include: " "DP" "&LDP" "&CCP";
print;
print " insurance coverage    loading";
print CIcov~CIload;
print "    X0        Xsqp ";
print X0~/*Xqnew*/Xsqp;
print;
print "Opt U0 = " /*-EUqnew*/-EUsqp;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print " Risk aversion    Time preference    intertemporal substitutability";
print a~b~r;
print;
print;
print "    Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio)    estimates    standard error    t-value    p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function " -EUqnew;

```

```

print;*/

end;

/**objective function to be maximized**/
proc EU(X);
    local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

print "X=" X;

    /*net income from hedging in the futures market*/
    for i (1, T, 1);
        /*assuming transaction costs paid at contract clearing*/
        FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
    endfor;

    C = NC + GI + CI + FI; /*print; print "mincC=" minc(C)*/;

d = d+1; print "d=" d;

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
endfor;
U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

    retp(-U0);
endp;

```

## Appendix C.4. Multi-period Additive Expected Utility (MA-EU) optimization for Whitman County (in GAUSS)

```

new;
cls;

print;
print;
print
"Multi-period expected utility (static) optimization for Whitman County Wheat producer

max Ut = sum (b^i*E(Ut+i)), i = 1,...,5

```

where  $U_t = - (1/C_t)$  s.t. CRR is set at 2 (ie,  $a = -1$ )

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```

library pgraph;
graphset;

```

```

pqqwin "many";

```

```

/**set up parameters**/

```

```

M = 2000;

```

```

N = 6; /*number of years included in the optimization*/

```

```

T = N-1; /*number of recursion in the optimization*/

```

```

U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/

```

```

/**note: the terminal value (T+1) of generalized expected utility = 0*/

```

```

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;

```

```

load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;

```

```

/*

```

```

for q (1, T, 1);

```

```

    hist(yield[.,q],50);

```

```

endfor;*/

```

```

boundval_z = minc(yield)./meanc(yield);

```

```

print "boundval_z =" boundval_z;

```

```

print;

```

```

print meanc(yield)~minc(yield)~stdc(yield);

```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = 0.5;
b = 0.89; /*beta*/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);

```

```

FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - transport)* (yld[65]) - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/

S0 = 550; /*the initial saving from before*/;
S0 = 0;

S = zeros(M,T);
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

X0 = X0_f/*X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[.,i] = (wcpri[.,i] - transport) .* yield[.,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[.,i] = maxc( ((LR-(wcpri[.,i]-transport)) ~ zeros(M,1))' ) .* yield[.,i];
    CCP[.,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[.,i]- transport)|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[.,i] = DP[1,i] + LDP[.,i] + CCP[.,i];
endfor;

```

```

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc(( CIcov * my[i] - yield[.,i] ~ zeros(M,1) ));
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

sqpSolveSet;

{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);

/**ouput**/
print;
print "    alpha    beta    transaction cost    production cost";
print a~b~trans~pc;
print;
print "Government Payment Programs include: " "DP" "&LDP" "&CCP";
print;
print " insurance coverage    loading";
print CIcov~CIload;
print;
print "    X0        Xsqp ";
print X0~Xsqp;
print;
print "Opt U0 = " -EUsqp;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print " Risk aversion    Time preference    intertemporal substitutability";
print a~b~r;
print;
print;
print "    Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio)    estimates    standard error    t-value    p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;

```



```

print;
print;
print "Value of objective function " -EUqnew;
print;*/

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, Unext, U0/*, sum_pre, loan_T*/;

  /**compute the simulated net consumption, a function of
  revenue, hedging, crop insurance, government program and loan**/

  print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI; print; print "mincC=" minc(C);

d = d+1; print "d=" d;

  /**compute the expected utility function recursively, starting from year T**/
  Unext= 0;
  for i (1, T, 1);
    Unext = Unext + b^i * meanc((C[.,i])^a/a);
  endfor;
  U0 = ( - (1/C0) + Unext); print; print "U0=" U0;

  retp(-U0);
endp;

```

## Appendix C.5. Generalized expected utility (GEU) optimization for Grant County (in GAUSS)

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Grant County Wheat producer
```

$$\max U_t = \{(1-b)C_t^r + b[Et((U_{t+1})^a)]^{(r/a)}\}^{(1/r)}$$

Based on simulated yield (stochastic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;
```

```
pqgwin "many";
```

```
/**set up parameters**/
```

```
M = 2000;
```

```
N = 6; /*number of years included in the optimization*/
```

```
T = N-1; /*number of recursion in the optimization*/
```

```
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/*include terminal (T+1) value of generalized expected utility*/
```

```
load yld[32,1] = D:\arec\grant_wyld72to03.txt;
```

```
load yield[2000,5] = D:\arec\grant_wyldsimuST_normal_5year.txt;
```

```
/*
```

```
for q (1, T, 1);
```

```
    hist(yield[:,q],50);
```

```
endfor;*/
```

```
boundval_z = minc(yield)./meanc(yield);
```

```
print "boundval_z =" boundval_z;
```

```
print;
```

```
print meanc(yield)~minc(yield)~stdc(yield);
```

```
/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
```

```
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
```

```

load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

/**transportation cost**/
transport = 0.47;

/**production cost**/
pc = 195;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.91; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);

```

```

C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - transport)* yld[32] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {0.1, 0.1, 0.1, 0.1, 0.1};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

X0 = X0_f/*X0_i*/;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[:,i] = (mwf[i] + 0.45) * maxc( ( CIcov * my[i] - yield[:,i] ) ~ zeros(M,1) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[:,i]);
    CI[:,i] = IP[:,i] - CIload * MIP[i];
endfor;

sqpSolveSet;

```

```

/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

QnewtonSet;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

/**ouput**/
print;
print "      alpha      beta      rho      transaction cost      production cost      transportation";
print a~b~r~trans~pc~transport;
print;
print "Government Payment Programs include: " "DP" "&LDP" "&CCP";
print;
print " insurance coverage      loading";
print CIcov~CIload;
print;
print "      X0      Xsqp ";
print X0~Xqnew/*Xsqp*/;
print;
print "Opt U0 = " -EUqnew/*-EUsqp*/;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "      Preference parameters";
print;
print " Risk aversion      Time preference      intertemporal substitutability";
print a~b~r;
print;
print;
print "      Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio)      estimates      standard error      t-value      p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function " -EUqnew;
print;*/

```

```

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, U0/*, sum_pre, loan_T*/;

  /**compute the simulated net consumption, a function of
  revenue, hedging, crop insurance, government program and loan**/

  print "X=" X;

  /**net income from hedging in the futures market*/
  for i (1, T, 1);
    /**assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI; /*print; print "mincC=" minc(C);*/

  d = d+1; print "d=" d;

  /**compute the expected utility function recursively, starting from year T**/
  U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
  for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
  endfor;
  U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0=" U0;

  retp(-U0);
endp;

```

## Appendix C.6. Multi-period Additive Expected Utility (MA-EU) optimization for Grant County (in GAUSS)

```

new;
cls;

print;
print;
print
"Multi-period expected utility (static) optimization for Grant County Wheat producer

max Ut = sum (b^i*E(Ut+i)), i = 1,...,5

    where Ut = - (1/Ct) s.t. CRR is set at 2 (ie, a = -1)

Based on simulated yield (stochastic trend) and price (stochastic trend) data

                                ---- ©2005 Wen Du. All rights reserved.  ";

library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[32,1] = D:\arec\grant_wyld72to03.txt;
load yield[2000,5] = D:\arec\grant_wyldsimuST_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);

```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
b = 0.89; /*beta*/

/**transportation cost**/
transport = 0.47;

/**production cost**/
pc = 195;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.91; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);

```



```

C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - transport)* yld[32] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price data**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

X0 = X0_f/*|X0_i*/;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[:,i] = (mwf[i] + 0.45) * maxc( (CIcov * my[i] - yield[:,i]) ~ zeros(M,1) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[:,i]);
    CI[:,i] = IP[:,i] - CIload * MIP[i];
endfor;

sqpSolveSet;

```

```

/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

QnewtonSet;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

/**ouput**/
print;
print "      beta      transaction cost  production cost  transportation";
print b~trans~pc~transport;
print;
print "Government Payment Programs include: " "DP" "&LDP" "&CCP";
print;
print " insurance coverage      loading";
print CIcov~CIload;
print;
print "      X0      Xsqp ";
print X0~Xqnew/*Xsqp*/;
print;
print "Opt U0 = " -EUqnew/*-EUsqp*/;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "      Preference parameters";
print;
print " Risk aversion  Time preference  intertemporal substitutability";
print a~b~r;
print;
print;
print "      Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio)  estimates  standard error  t-value  p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function  " -EUqnew;
print;*/

```

```

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, Unext, U0/*, sum_pre, loan_T*/;

  /**compute the simulated net consumption, a function of
  revenue, hedging, crop insurance, government program and loan**/

  print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI; print; print "mincC=" minc(C);

  d = d+1; print "d=" d;

  /**compute the expected utility function recursively, starting from year T**/
  Unext= 0;
  for i (1, T, 1);
    Unext = Unext + b^i * meanc(-1/(C[.,i])); /*alpha = -1 implicitly*/
  endfor;
  U0 = ( - (1/C0) + Unext); print; print "U0=" U0;

  retp(-U0);
endp;

```

**APPENDIX D: COMPUTER PROGRAMS FOR CHAPTER 3**

**Appendix D.1. The Impact of Risk Aversion on Optimal Risk Management Portfolios,  
based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)
```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsимуDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);
```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

for alpha (-6, 0.6, 0.1);
    a = alpha;

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);

```

```

CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f/*X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)'|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];
endfor;

```

```

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc(( CIcov * my[i] - yield[.,i]) ~ zeros(M,1) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

sqpSolveSet;
/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

/**ouput**/
print;
print "Given  beta = " b "    rho = " r;
print "    alpha = " a;
print;
print " transaction cost  production cost  insurance coverage    loading";
print trans~pc~CIcov~CIload;
print;
print "    X0          Xsqp ";
print X0~Xqnew/*Xsqp*/;
print;
print "Opt U0 = " -EUqnew/*-EUsqp*/;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdp(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print " Risk aversion  Time preference  intertemporal substitutability";
print a~b~r;
print;

```



```

print;
print "      Optimization Results by sqpSolve";
print;
print "  initial values (hedging ratio)  estimates  standard error  t-value  p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function  " -EUqnew;
print;*/

endfor;

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI;
  print;
  print "      meanC      stdC";
  print meanc(C)~stdc(C);

  /*saving/loan is the deducted term in the consumption**/
  C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
  for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
  endfor;
  C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
*/

d = d+1; print "d=" d;

```

```

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ( (1-b)*C[.,T]^r )^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ( (1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a) )^(1/r);
endfor;
U0 = ( (1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a) )^(1/r); print; print "U0 = " U0;

    retp(-U0);
endp;

```

**Appendix D.2. The Impact of Time Preference on Optimal Risk Management Portfolios,  
based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)
```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsимуDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);
```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

for beta (0.1, 0.9, 0.1);
    b = beta;

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);

```

```

CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f/*X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)'|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];
endfor;

```

```

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc(( CIcov * my[i] - yield[.,i]) ~ zeros(M,1) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

sqpSolveSet;
/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

/**ouput**/
print;
print "Given  beta = " b "    rho = " r;
print "    alpha = " a;
print;
print " transaction cost  production cost  insurance coverage    loading";
print trans~pc~CIcov~CIload;
print;
print "    X0          Xsqp ";
print X0~Xqnew/*Xsqp*/;
print;
print "Opt U0 = " -EUqnew/*-EUsqp*/;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdp(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print " Risk aversion  Time preference  intertemporal substitutability";
print a~b~r;
print;

```

```

print;
print "      Optimization Results by sqpSolve";
print;
print "  initial values (hedging ratio)  estimates  standard error  t-value  p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function  " -EUqnew;
print;*/

endfor;

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI;
  print;
  print "      meanC      stdC";
  print meanc(C)~stdc(C);

  /*saving/loan is the deducted term in the consumption**/
  C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
  for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
  endfor;
  C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
  */

d = d+1; print "d=" d;

```

```

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
endfor;
U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

    retp(-U0);
endp;

```



**Appendix D.3. The Impact of Intertemporal Substitutability on Optimal Risk Management Portfolios, based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)
```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

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```
library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[:,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);
```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

for rho (-6, 0.9, 0.1);
    r = rho;

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures constract*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);

```

```

LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f/*|X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[:,i] = maxc( ((LR-(wcpri[:,i]-transport)) ~ zeros(M,1))' ) .* yield[:,i];
    CCP[:,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[:,i]- transport)'|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[:,i] = DP[1,i] + LDP[:,i] + CCP[:,i];

```

```

endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc(( (CIcov * my[i] - yield[.,i]) ~ zeros(M,1) ));
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

sqpSolveSet;
/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

/**ouput**/
print;
print "Given  beta = " b "    rho = " r;
print "    alpha = " a;
print;
print " transaction cost  production cost  insurance coverage    loading";
print trans~pc~CIcov~CIload;
print;
print "    X0          Xsqp";
print X0~Xqnew/*Xsqp*/
print;
print "Opt U0 = " -EUqnew/*-EUsqp*/;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdp(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print " Risk aversion  Time preference  intertemporal substitutability";
print a~b~r;

```

```

print;
print;
print "          Optimization Results by sqpSolve";
print;
print "  initial values (hedging ratio)  estimates  standard error  t-value  p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function  " -EUqnew;
print;*/

endfor;

end;

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI;
  print;
  print "    meanC    stdC";
  print meanc(C)~stdc(C);

  /*saving/loan is the deducted term in the consumption**/
  C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
  for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
  endfor;
  C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
*/

```

```

d = d+1; print "d=" d;

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
endfor;
U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

    retp(-U0);
endp;

```

**Appendix D.4. The Impact of Transaction Cost on Optimal Risk Management Portfolios, based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```

new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)

```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```

library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsимуDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);

```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transacion cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);

```



```

MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f/*X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[.,i] = (wcpri[.,i] - transport) .* yield[.,i] - pc;
endfor;

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[.,i] = maxc( ((LR-(wcpri[.,i]-transport)) ~ zeros(M,1))' ) .* yield[.,i];
    CCP[.,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[.,i]- transport)'|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[.,i] = DP[1,i] + LDP[.,i] + CCP[.,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);

```

```

        IP[:,i] = (mwf[i] + 0.45) * maxc(( CIcov * my[i] - yield[:,i]) ~ zeros(M,1) ));
        MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[:,i]);
        CI[:,i] = IP[:,i] - CIload * MIP[i];
    endfor;

/**transacion cost of futures construct*/
mm = 21; /*number of intervals in Transaction Cost within the range*/

trans = zeros(mm,1);
Xtrans = zeros(T,mm);
EUtrans = zeros(mm,1);

for kk (1,mm,1);

trans[kk] = 0 + (kk - 1) * 0.001 ;
TC = trans[kk];

sqpSolveSet;
/*
{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);*/

Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0);

Xtrans[:,kk] = Xsqp;
EUtrans[kk] = -EUsqp;

endfor;

/**ouput**/
print;
print "    alpha        beta        rho    " /*transaction cost*/;
print a~b~r/*~trans*/;
print;
print " insurance coverage    loading";
print CIcov~CIload;
print;
print "Government Payment Programs include: " "DP" "&LDP" /*"&CCP"*/;
print;
print "    X0            Xsqp ";
print X0~Xsqp;
print;
print "Opt U0 = " -EUsqp;
print;*/

```

```

print " Transaction Cost           Optimal Hedging Ratios (Short Positions)
";
print trans~-Xtrans';
print;
print "Opt U0";
print EUtrans;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdp(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print " Preference parameters";
print;
print " Risk aversion Time preference intertemporal substitutability";
print a~b~r;
print;
print;
print " Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio) estimates standard error t-value p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print " Transaction Cost           Optimal Hedging Ratios (Short Positions)
";
print trans~-Xtrans';
print;
print "Opt U0";
print EUtrans;
print;

end;

/**objective function to be maximized**/
proc EU(X);
local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

```

```

print "X=" X;

/*net income from hedging in the futures market*/
for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
endfor;

C = NC + GI + CI + FI;
print;
print "    meanC    stdC";
print meanc(C)~stdc(C);

/*saving/loan is the deducted term in the consumption*/
C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
endfor;
C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
*/

d = d+1; print "d=" d;

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
endfor;
U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

retp(-U0);
endp;

```

**Appendix D.5. The Impact of Target Price on Optimal Risk Management Portfolios, based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)
```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);
```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transacion cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**target price variation from 2.86 to 3.92 in CCP*/
mm = 57; /*number of intervals in Transaction Cost within the range*/

target = zeros(mm,1);
Xpt = zeros(T,mm);
EUpt = zeros(mm,1);

for kk (1,m,1);

```

```

target[kk] = 2.86 + (kk - 1) * 0.02 ;
PT = target[kk];

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f/*|X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

```

```

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[.,i] = maxc( ((LR-(wcpri[.,i]-transport)) ~ zeros(M,1))' ) .* yield[.,i];
    CCP[.,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[.,i]- transport)|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[.,i] = DP[1,i] + LDP[.,i] + CCP[.,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc( ( (CIcov * my[i] - yield[.,i]) ~ zeros(M,1) ) );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

/**transcation cost of futures construct*/
mm = 21; /*number of intervals in Transaction Cost within the range*/

trans = zeros(mm,1);
Xtrans = zeros(T,mm);
EUtrans = zeros(mm,1);

for kk (1,mm,1);

trans[kk] = 0 + (kk - 1) * 0.001 ;
TC = trans[kk];

sqpSolveSet;

{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);

Xpt[.,kk] = Xsqp;
EUpt[kk] = -EUsqp;

print "kk=" kk;
/*
Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0); */

endfor;

/**ouput**/
print;
print "    alpha    beta    rho    " /*transaction cost*/;
print a~b~r/*~trans*/;

```



```

print;
print " insurance coverage    loading";
print CIcov~CIload;
print;
print "Government Payment Programs include: " "DP" "&LDP" /*"&CCP"*/;
print;
print "      X0          Xsqp ";
print X0~Xsqp;
print;
print "Opt U0 = " -EUsqp;
print;*/
print "   Target Price          Optimal Hedging Ratios (Short Positions)
";
print target~-Xpt';
print;
print   "Opt U0";
print EUpt;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "      Preference parameters";
print;
print " Risk aversion  Time preference  intertemporal substitutability";
print a~b~r;
print;
print;
print "      Optimization Results by sqpSolve";
print;
print " initial values (hedging ratio)  estimates  standard error  t-value  p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function " -EUsqp;
print;*/

end;

```

```

/**objective function to be maximized**/
proc EU(X);
  local i,j, k, U0;

  /**compute the simulated net consumption, a function of
  revenue, hedging, crop insurance, government program and loan**/

  print "X=" X;

  /*net income from hedging in the futures market*/
  for i (1, T, 1);
    /*assuming transaction costs paid at contract clearing*/
    FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
  endfor;

  C = NC + GI + CI + FI;
  print;
  print "      meanC      stdC";
  print meanc(C)~stdc(C);

  /*saving/loan is the deducted term in the consumption**/
  C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
  for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
  endfor;
  C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
  */

  d = d+1; print "d=" d;

  /**compute the expected utility function recursively, starting from year T**/
  U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
  for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
  endfor;
  U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

  retp(-U0);
endp;

```

**Appendix D.6. The Impact of Loan Rate on Optimal Risk Management Portfolios, based on Generalized expected utility (GEU) optimization for Whitman County (in GAUSS)**

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer

max Ut = {(1-b)*Ct^r + b*[Et((Ut+1)^a)]^(r/a)}^(1/r)
```

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;

pqqwin "many";

/**set up parameters**/
M = 2000;
N = 6; /*number of years included in the optimization*/
T = N-1; /*number of recursion in the optimization*/
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
/**note: the terminal value (T+1) of generalized expected utility = 0*/

load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;

/*
for q (1, T, 1);
    hist(yield[.,q],50);
endfor;*/

boundval_z = minc(yield)./meanc(yield);
print "boundval_z =" boundval_z;
print;
print meanc(yield)~minc(yield)~stdc(yield);
```

```

/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transacion cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /* target price*/
LR = 0; /*loan rate variate from 0 to 2.86*/

mm = 25; /*number of intervals in Transaction Cost within the range*/

loan = zeros(mm,1);
Xlr = zeros(T,mm);
EUlr = zeros(mm,1);

for kk (1,m,1);

```

```

loan[kk] = 0 + (kk - 1) * 0.04 ;
LR = loan[kk];

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
GI = zeros(M,T);
DP = zeros(1,T);
LDP = zeros(M,T);
CCP = zeros(M,T);
CI = zeros(M,T);
IP = zeros(M,T);
MIP = zeros(T,1);
FI = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - 0.5)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/
interest = 0.08; /*annual interest rate 8% for loans*/
interest = (1/b) - 1;

/**starting values of percentage of hedging for estimation**/
/**note: although indexed as x1-x5 and z1-z5, what to be estimated are decisions made at t=0-4
therefore the index of X0 is not consistent with that of yield and price**/

/*starting values of (hedging ratio), ie x(t-1), from grid search, given X2 = -0.3 and rest = -0.1*/
X0_f = {-0.3, -0.2, -0.2, -0.3, -0.2};

/*starting values of crop insurance coverage, ie z(t-1)*/
X0_i = {0.8, 0.8, 0.8, 0.8, 0.8};
X0_i = {0.85, 0.85, 0.85, 0.85, 0.85};

/* starting values of loan/saving level*/
X0_s = {247.6176, 108.4933, 44.2531, 14.2805};

X0 = X0_f|X0_i */;

d = 0;

/*net income from production*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

```

```

/*net income from government program*/
for i (1, T, 1);
    DP[1,i] = PD * 0.85 * 0.9 * my[i];
    LDP[.,i] = maxc( ((LR-(wcpri[.,i]-transport)) ~ zeros(M,1))' ) .* yield[.,i];
    CCP[.,i] = maxc( zeros(1,M)|(PT-PD - maxc((wcpri[.,i]- transport)|(LR*ones(1,M))))' ) *
0.85 * 0.935 * my[i];
    GI[.,i] = DP[1,i] + LDP[.,i] + CCP[.,i];
endfor;

/*net income from crop insurance*/
for i (1, T, 1);
    IP[.,i] = (mwf[i] + 0.45) * maxc( ( (CIcov * my[i] - yield[.,i]) ~ zeros(M,1) )' );
    MIP[i] = ((300 - 790 * CIcov + 600 * CIcov^2) / 100) * meanc(IP[.,i]);
    CI[.,i] = IP[.,i] - CIload * MIP[i];
endfor;

sqpSolveSet;

{Xsqp, EUsqp, lagr, retsqp} = sqpSolve(&EU, X0);

Xlr[.,kk] = Xsqp;
EUIr[kk] = -EUsqp;

print "kk=" kk;

/*
Qnewtonset;
{Xqnew, EUqnew, lagrqnew, retqnew} = Qnewton(&EU, X0); */

endfor;

/**ouput**/
print;
print "    alpha        beta        rho    " /*transaction cost*/;
print a~b~r/*~trans*/;
print;
print " insurance coverage    loading";
print CIcov~CIload;
print;
print "Government Payment Programs include: " "DP" "&LDP" /*"&CCP"*/;
print;
print "    X0            Xsqp ";
print X0~Xsqp;
print;
print "Opt U0 = " -EUsqp;
print;*/

```

```

print "    Loan Rate                Optimal Hedging Ratios (Short Positions)
";
print loan~Xlr';
print;
print "    Opt U0";
print EUlr;
print;
print;

/*
hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdp(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "    Preference parameters";
print;
print "    Risk aversion    Time preference    intertemporal substitutability";
print a~b~r;
print;
print;
print "    Optimization Results by sqpSolve";
print;
print "    initial values (hedging ratio)    estimates    standard error    t-value    p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function " -EUsqp;
print;*/

end;

/**objective function to be maximized**/
proc EU(X);
    local i,j, k, U0;

/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/

print "X=" X;

    /*net income from hedging in the futures market*/
    for i (1, T, 1);

```

```

/*assuming transaction costs paid at contract clearing*/
FI[.,i] = X[i] * my[i] * (wfpri[.,i] - meanc(wfpri[.,i])) - trans * abs(X[i]) * my[i];
endfor;

C = NC + GI + CI + FI;
print;
print "    meanC    stdC";
print meanc(C)~stdc(C);

/*saving/loan is the deducted term in the consumption**/
C[.,1] = (1 + interest) * S0 + (NC[.,1] + GI[.,1] + FI[.,1] + CI[.,1]) - X[2*T+1];
for i (2, T-1, 1);
    j = i + 2 * T;
    C[.,i] = (1 + interest) * X[j-1] + (NC[.,i] + GI[.,i] + FI[.,i] + CI[.,i]) - X[j];
endfor;
C[.,T] = (1 + interest) * X[3*T-1] + (NC[.,T] + GI[.,T] + FI[.,T] + CI[.,T]) - (1 + interest)^T *
550;
*/

d = d+1; print "d=" d;

/**compute the expected utility function recursively, starting from year T**/
U[.,T] = ((1-b)*C[.,T]^r)^(1/r); /*U(T+1) = 0*/
for i (T-1, 1, -1);
    U[.,i] = ((1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a))^(1/r);
endfor;
U0 = ((1-b)*C0^r + b*(meanc(U[.,1]^a))^(r/a))^(1/r); print; print "U0 = " U0;

retp(-U0);
endp;

```



## Appendix D.7. Computation of CE for Risk Management Portfolios (in GAUSS)

```
new;
cls;

print;
print;
print
"Generalized expected utility (GEU) optimization for Whitman County Wheat producer
```

$$\max U_t = \{(1-b)C_t^r + b[Et((U_{t+1})^a)]^{(r/a)}\}^{(1/r)}$$

Based on simulated yield (deterministic trend) and price (stochastic trend) data

---- ©2005 Wen Du. All rights reserved. ";

```
library pgraph;
graphset;
```

```
pqgwin "many";
```

```
/**set up parameters**/
```

```
M = 2000;
```

```
N = 6; /*number of years included in the optimization*/
```

```
T = N-1; /*number of recursion in the optimization*/
```

```
U = zeros(M,T); /*initialize utility matrix, where M = number of samples*/
```

```
/**note: the terminal value (T+1) of generalized expected utility = 0*/
```

```
load yld[65,1] = D:\arec\whitman_wyld39to03.txt;
```

```
load yield[2000,5] = D:\arec\whitman_wyldsimuDTreg_normal_5year.txt;
```

```
/*
```

```
for q (1, T, 1);
```

```
    hist(yield[:,q],50);
```

```
endfor;*/
```

```
boundval_z = minc(yield)./meanc(yield);
```

```
print "boundval_z =" boundval_z;
```

```
print;
```

```
print meanc(yield)~minc(yield)~stdc(yield);
```

```
/*load yield[2000,5] = D:\arec\yield_simulation_5year.txt;*/
```

```

load wcpri[M,T] = D:\arec\wcpri_simuST_normal_5year.txt; /*print "wcpri=" wcpri;*/
load wfpri[M,T] = D:\arec\wfpri_adj_simuST_normal_5year.txt; /*print "wfpri=" wfpri*/;
/*print meanc(wfpri-meanc(wfpri));*/

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**optimal level of U0**/
MaxU0 = 116.86911;

/**change the price units from cents into dollars**/
wfpri = wfpri / 100; /*print "wfpri - meanc(wfpri)" wfpri - meanc(wfpri);*/
wcpri = wcpri / 100;

mwf = meanc(wfpri);
mwc = meanc(wcpri);
my = meanc(yield); /*print "my=" my;*/

/**initialization of the parameters, given by previous studies**/
a = -0.13; /*alpha*/
b = 0.89; /*beta*/
r = 0.9493; /*rho*/

/**transportation cost**/
transport = 0.5;

/**production cost**/
pc = 203;

/**transcation cost of futures construct*/
trans = 0.017;

/**crop insurance coverage level, choose from {0.85, 0.8, 0.75, 0.7}**/
CIcov = 0.85;

/**corp insurance contract loading, choose from {1(0%), 1.3(30%)}**/
CIload = 1;

/**government programs set prices**/
PD = 0.52; /*directly payment rate*/
PT = 3.92; /*target price*/

```

```

LR = 2.86; /*loan rate = 2.86 for Whitman; 2.91 for Grant*/

/**initialize the variables of different risk manage tools for estimation**/
NC = zeros(M,T);
C = zeros(M,T);

wcpri0 = 3.87; /*the latest (2003) wheat cash price, from historical data*/
C0 = (wcpri0 - transport)* yld[65] - pc; /*the latest consumption level, from historical data*/

wfpri0 = 3.585; /*the latest (2003) wheat futures price, from historical data*/

/*Compute the income from Cash market only for next five years*/
for i (1, T, 1);
    NC[:,i] = (wcpri[:,i] - transport) .* yield[:,i] - pc;
endfor;

d = 0;

CE =800;

sqpSolveSet;

_sqp_Bounds = { 0 1e256 };

{CEsqp, CEsqp, lagr, retsqp} = /*Qnewton*/sqpSolve(&EU, CE);

/**ouput**/
print; /*
print " transaction cost production cost";
print trans~pc;
print;
print "Government Payment Programs include: " "DP" "&LDP" "&CCP";
print;
print " insurance coverage loading";
print CIcov~CIload;
print;
print " X0 Xsqp ";
print X0~Xsqp
print;
print;
print " MaxU0 CEsqp ";
print MaxU0~CEsqp;
print;
print;

/*

```

```

hsqp = hessp(&EU, Xsqp);
print "det(hsqp=)" det(hsqp);
stdsqp = sqrt(diag(invdpd(hsqp)));
tsqp = Xsqp./stdsqp;
psqp = 2 * cdfnc(abs(tsqp));

print;
print "      Preference parameters";
print;
print " Risk aversion   Time preference   intertemporal substitutability";
print a~b~r;
print;
print;
print "      Optimization Results by sqpSolve";
print;
print "  initial values (hedging ratio)   estimates   standard error   t-value   p-value";
print X0~Xsqp~stdsqp~tsqp~psqp;
print;
print;
print "Value of objective function   " -EUsqp;
print;*/

```

```
end;
```

```
/**objective function to be maximized**/
```

```
proc EU(X);
```

```
  local i,j, k, U0, distance;
```

```
/**compute the simulated net consumption, a function of
revenue, hedging, crop insurance, government program and loan**/
```

```
print "X=" X;
```

```
  C = NC + X /**/; print; print "mincC=" minc(C);
```

```
d = d+1; print "d=" d;
```

```
/**compute the expected utility function recursively, starting from year T**/
```

```
  U[.,T] = ( (1-b)*C[.,T]^r )^(1/r); /*U(T+1) = 0*/
```

```
  for i (T-1, 1, -1);
```

```
    U[.,i] = ( (1-b)*C[.,i]^r + b*(meanc(U[.,i+1]^a))^(r/a) )^(1/r);
```

```
  endfor;
```

```
  U0 = ( (1-b)*(C0)^r + b*(meanc(U[.,1]^a))^(r/a) )^(1/r); print; print "U0 = " U0;
```

```
    retp((U0 - MaxU0)^2);  
endp;
```

**APPENDIX E: COMPUTER PROGRAMS FOR CHAPTER 4**

## Appendix E.1. Augmented Dickey-Full Test of the CZCE and CBOT Wheat Futures Prices

(in SAS)

```
options linesize=79 pageno=1 nodate;  
options formdlm=' ';
```

```
TITLE "ADF test of wheat futures prices: CZCE vs. CBOT
```

```
--- © 2005 Wen Du. All rights Reserved ";
```

```
Latest update: 2/4/2004
```

```
*/
```

```
data wADF;  
input CBOT CZCE;  
cards;  
843.9557 1193  
853.0795 1174  
849.2779 1173  
860.6827 1158  
866.7653 1153  
881.9717 1161  
897.1781 1147  
901.7400 1145  
898.6987 1133  
904.0210 1114  
902.5003 1133  
897.1781 1138  
904.7813 1150  
900.2194 1152  
886.5336 1108  
898.6987 1084  
888.0542 1088  
876.6494 1076  
882.7320 1064  
879.6907 1059  
918.4671 1038  
907.0622 1050  
906.3019 1053  
897.1781 1065  
906.3019 1057  
897.1781 1060  
874.3685 1057  
878.9304 1057
```

851.5589	1061
843.9557	1073
853.0795	1058
854.6001	1057
851.5589	1056
851.5589	1055
856.8811	1055
856.8811	1075
862.2033	1070
867.5256	1060
858.4017	1060
866.7653	1062
890.3352	1060
884.2526	1062
876.6494	1069
894.8971	1069
877.4097	1066
861.4430	1064
866.0049	1064
849.2779	1061
838.6334	1060
842.4350	1062
827.2286	1061
834.0715	1058
846.2366	1055
866.7653	1072
853.8398	1057
848.5176	1059
849.2779	1058
841.6747	1057
856.1208	1056
838.6334	1056
839.3937	1058
848.5176	1059
855.3605	1057
847.7573	1063
842.4350	1063
837.1128	1061
841.6747	1058
836.3524	1058
836.3524	1063
841.6747	1062
829.5096	1061
809.7412	1061
810.5016	1064
851.5589	1060



850.0382	1065
869.8065	1070
891.0955	1075
897.9384	1076
892.6162	1088
887.2939	1090
878.1701	1088
861.4430	1091
874.3685	1090
887.2939	1092
890.3352	1088
885.7733	1090
885.7733	1100
889.5749	1100
869.8065	1099
872.0875	1094
859.1621	1097
862.2033	1103
846.2366	1097
850.0382	1100
840.1540	1098
847.7573	1094
859.1621	1097
843.9557	1090
841.6747	1090
831.0302	1097
837.1128	1098
837.1128	1096
852.3192	1092
868.2859	1091
878.1701	1100
881.2114	1090
865.2446	1089
871.3272	1087
867.5256	1087
864.4843	1093
866.0049	1094
824.9476	1090
783.1300	1091
786.9316	1089
775.5268	1137
774.7665	1090
781.6094	1096
779.3284	1099
767.9236	1095
774.0062	1104

756.5188	1100
742.8330	1107
733.7092	1100
743.5934	1100
750.4362	1100
751.9569	1099
746.6346	1099
746.6346	1099
742.8330	1099
747.3950	1099
754.2378	1099
748.9156	1092
745.1140	110
748.9156	1107
736.7505	1108
720.7837	1108
710.1393	1108
719.2631	1100
716.2218	1105
716.9821	1097
720.0234	1095
725.3457	1100
731.4282	1097
740.5521	1100
728.3869	1097
726.1060	1098
718.5028	1101
713.9409	1101
710.8996	1095
729.9076	1095
734.4695	1095
737.5108	1108
761.0807	1092
748.9156	1099
762.6014	1096
761.0807	1096
769.4443	1096
752.7172	1096
758.7998	1096
761.8410	1096
758.0394	1096
745.1140	1096
735.9902	1096
735.9902	1096
903.2606	1096
914.6654	1096

893.3765	1096
896.4178	1096
889.5749	1096
899.4590	1539
908.5829	1531
910.8638	1527
921.5083	1535
923.0290	1536
936.7147	1533
945.8386	1549
970.1688	1550
971.6895	1535
968.6482	1497
945.8386	1472
958.0037	1467
948.8799	1464
936.7147	1452
927.5909	1454
929.1115	1453
916.9464	1447
918.4671	1427
912.3845	1424
916.9464	1426
924.5496	1421
913.9051	1421
914.6654	1423
913.1448	1427
924.5496	1428
941.2767	1427
939.7560	1429
937.4751	1424
945.8386	1413
927.5909	1418
924.5496	1402
929.8719	1403
923.0290	1408
916.9464	1406
921.5083	1415
925.3099	1418
924.5496	1419
921.5083	1420
929.1115	1417
938.2354	1412
929.1115	1432
923.0290	1430
913.9051	1440

923.7893	1433
933.6735	1431
938.9957	1437
933.6735	1426
935.1941	1434
916.9464	1440
922.2687	1442
918.4671	1450
916.1861	1452
916.1861	1449
909.3432	1449
902.5003	1450
910.8638	1446
923.0290	1444
916.9464	1442
923.0290	1446
931.3925	1443
928.3512	1443
920.7480	1432
919.9877	1424
943.5576	1425
934.4338	1428
954.9624	1422
959.5244	1423
958.0037	1421
954.9624	1409
961.8053	1414
973.9704	1414
973.9704	1410
975.4911	1408
963.3260	1410
957.2434	1410
963.3260	1396
964.8466	1405
919.9877	1400
912.3845	1390
916.1861	1365
913.9051	1361
912.3845	1357
899.4590	1339
903.2606	1341
914.6654	1349
913.9051	1351
909.3432	1353
909.3432	1361
898.6987	1352

888.8146	1348
888.0542	1342
886.5336	1318
883.4923	1318
904.7813	1335
904.0210	1333
912.3845	1339
924.5496	1343
921.5083	1349
913.9051	1350
915.4258	1349
914.6654	1345
932.1528	1338
931.3925	1340
924.5496	1330
897.1781	1328
884.2526	1343
879.6907	1348
888.0542	1349
876.6494	1359
856.1208	1373
862.2033	1366
877.4097	1366
875.8891	1366
868.2859	1364
870.5669	1361
843.1953	1363
853.0795	1353
863.7240	1327
870.5669	1319
869.8065	1310
863.7240	1310
856.1208	1296
848.5176	1297
859.1621	1300
878.1701	1302
887.2939	1298
872.0875	1298
881.2114	1286
877.4097	1285
875.8891	1289
867.5256	1299
866.7653	1296
881.9717	1291
887.2939	1309
872.0875	1305

892.6162	1303
846.2366	1302
840.9144	1297
849.2779	1286
855.3605	1272
878.1701	1268
873.6081	1271
868.2859	1275
869.8065	1264
857.6414	1264
831.7905	1238
821.9064	1227
821.9064	1230
826.4683	1228
820.3857	1230
835.5921	1206
833.3112	1199
842.4350	1197
853.8398	1202
834.0715	1215
824.1873	1212
825.7080	1205
837.1128	1233
835.5921	1230
830.2699	1233
834.0715	1227
831.0302	1234
823.4270	1233
812.0222	1234
833.3112	1239
829.5096	1247
810.5016	1243
810.5016	1231
798.3364	1215
780.0887	1208
788.4523	1204
785.4110	1206
774.0062	1212
784.6507	1209
793.7745	1228
801.3777	1215
811.2619	1219
816.5841	1211
815.0635	1216
824.1873	1216
829.5096	1217

879.6907	1213
871.3272	1213
857.6414	1210
881.9717	1211
878.1701	1205
878.9304	1204
861.4430	1199
862.2033	1196
859.1621	1198
859.1621	1193
854.6001	1185
852.3192	1181
842.4350	1173
846.9969	1154
834.8318	1150
819.6254	1153
805.1793	1154
805.9396	1156
812.0222	1153
816.5841	1155
824.1873	1153
821.9064	1155
825.7080	1164
817.3444	1161
810.5016	1161
812.0222	1162
812.7825	1164
809.7412	1159
815.0635	1160
821.9064	1163
843.1953	1159
834.0715	1158
831.7905	1145
819.6254	1130
836.3524	1126
825.7080	1122
845.4763	1105
840.9144	1093
835.5921	1093
822.6667	1095
818.8651	1116
824.1873	1096
834.8318	1074
812.0222	1074
916.9464	1084
901.7400	1063

892.6162	1083
901.7400	1079
901.7400	1240
907.8226	1233
909.3432	1238
901.7400	1236
898.6987	1237
890.3352	1237
878.9304	1232
875.8891	1229
881.9717	1229
883.4923	1228
881.9717	1228
878.9304	1225
885.0130	1232
891.0955	1210
895.6574	1208
907.8226	1211
901.7400	1216
907.8226	1231
906.3019	1234
919.9877	1233
938.2354	1241
926.0703	1259
932.1528	1261
929.1115	1253
921.5083	1246
916.9464	1250
919.9877	1236
923.0290	1226
930.6322	1201
921.5083	1191
921.5083	1209
913.9051	1220
901.7400	1217
910.8638	1217
910.8638	1218
919.9877	1193
923.0290	1200
918.4671	1192
921.5083	1185
919.9877	1171
894.1368	1153
892.6162	1157
883.4923	1152
881.9717	1162



903.2606	1166
894.1368	1177
891.0955	1166
891.0955	1167
885.0130	1174
883.4923	1159
886.5336	1147
885.0130	1148
874.3685	1151
885.0130	1153
883.4923	1163
883.4923	1163
889.5749	1164
875.8891	1159
875.8891	1153
866.7653	1156
878.1701	1151
876.6494	1155
910.8638	1179
907.8226	1188
905.5416	1177
906.3019	1184
924.5496	1184
930.6322	1185
923.7893	1176
924.5496	1179
923.7893	1177
918.4671	1166
912.3845	1153
917.7067	1148
921.5083	1152
929.1115	1150
907.8226	1151
906.3019	1151
902.5003	1145
904.0210	1151
909.3432	1155
897.1781	1153
898.6987	1152
891.0955	1151
894.1368	1152
895.6574	1147
883.4923	1143
889.5749	1145
885.0130	1150
888.0542	1151

878.9304	1155
874.3685	1154
873.6081	1153
868.2859	1152
879.6907	1146
877.4097	1146
890.3352	1146
890.3352	1148
882.7320	1156
878.1701	1154
868.2859	1159
875.8891	1157
870.5669	1157
877.4097	1156
883.4923	1160
875.8891	1163
880.4510	1161
871.3272	1158
882.7320	1157
881.2114	1159
883.4923	1158
894.8971	1160
912.3845	1163
894.8971	1164
896.4178	1165
894.8971	1169
895.6574	1168
886.5336	1168
878.9304	1166
867.5256	1164
859.1621	1167
866.7653	1165
861.4430	1158
866.0049	1152
866.0049	1152
877.4097	1152
878.1701	1153
859.1621	1155
855.3605	1155
850.7985	1156
850.0382	1155
843.9557	1154
837.1128	1155
829.5096	1145
827.2286	1137
837.8731	1131

846.2366	1131
846.9969	1133
843.9557	1133
863.7240	1137
862.9637	1140
875.1288	1136
855.3605	1136
847.7573	1132
856.8811	1134
846.9969	1141
836.3524	1146
842.4350	1149
835.5921	1148
844.7160	1146
859.9224	1150
859.9224	1149
877.4097	1155
891.8558	1153
878.9304	1159
881.9717	1160
875.1288	1166
862.2033	1171
871.3272	1177
872.8478	1179
886.5336	1183
919.9877	1179
914.6654	1177
900.9797	1179
899.4590	1183
906.3019	1184
907.8226	1179
897.9384	1189
911.6242	1189
911.6242	1195
915.4258	1197
954.9624	1192
951.9211	1193
980.8133	1196
974.7308	1195
979.2927	1194
981.5736	1186
964.0863	1189
974.7308	1189
987.6562	1181
983.0943	1178
967.8879	1177

984.6149	1179
1015.7881	1179
1018.8293	1177
1013.5071	1179
1005.9039	1181
1033.2754	1185
1011.9865	1187
1021.8706	1181
1018.8293	1182
1018.8293	1185
992.9784	1184
991.4578	1175
1015.7881	1169
1018.0690	1171
1024.9119	1167
1027.9532	1168
1039.3580	1171
1053.0438	1169
1029.4738	1169
1047.7215	1169
1069.7708	1170
1084.9772	1169
1085.7375	1171
1065.9692	1174
1057.6057	1178
1062.1676	1175
1030.2341	1175
1028.7135	1176
1034.7961	1177
1057.6057	1170
1075.0931	1165
1072.0518	1162
1080.4153	1160
1080.4153	1159
1101.7043	1165
1116.1504	1155
1152.6457	1155
1175.4553	1165
1227.1571	1166
1262.1319	1166
1259.0906	1168
1265.1732	1168
1243.8842	1168
1201.3062	1162

;

```
title2 "unit root test of CZCE prices";  
%DFTEST(WADF, CZCE, AR=1, OUT=R1, OUTSTAT=OUTS1, TREND=0);  
PROC PRINT DATA=OUTS1;  
RUN;  
PROC ARIMA DATA=R1;  
    IDENTIFY VAR=R;  
RUN;
```

```
title2 "unit root test of CBOT prices";  
%DFTEST(WADF, CBOT, AR=1, OUT=R2, OUTSTAT=OUTS2, TREND=2);  
PROC PRINT DATA=OUTS2;  
RUN;  
PROC ARIMA DATA=R2;  
    IDENTIFY VAR=R;  
RUN;
```

## Appendix E.2. Normality Check of the CBOT and CZCE Wheat Futures Prices (in SAS)

```
options linesize=79 pageno=1 nodate;
options formdlm=' ';

TITLE " Normality check of CBOT and CZCE price changes --- WEN DU
      --- © 2005 Wen Du. All rights Reserved ";
";

title1 " CBOT normality check";

DATA cbot; INFILE 'd:\arec\CBOTWX_noSD.txt';
  input cbot_nor;
RUN;

/*normality checking of CBOT first difference prices*/
proc univariate normal plot;
var cbot_nor;
run;

/* creating a normal probability plot*/
proc rank normal=blom;
ranks cbotr_nor;
var cbot_nor;
run;

proc plot;
plot cbot_nor*cbotr_nor;
proc corr ;
var cbot_nor cbotr_nor;
run;

title1 " CZCE normality check";

DATA czce; INFILE 'd:\arec\CZCEWX_noSD.txt';
  input czce_nor;
RUN;

/*normality checking of CZCE first difference prices*/
proc univariate normal plot;
var czce_nor;
run;

/* creating a normal probability plot*/
proc rank normal=blom;
```

```
ranks czcer_nor;  
var czce_nor;  
run;
```

```
proc plot;  
plot czce_nor*czcer_nor;  
proc corr ;  
var czce_nor czcer_nor;  
run;  
QUIT;
```

### Appendix E.3. Univariate time series estimation of CZCE Prices (in SAS)

```
options linesize=79 pageno=1 nodate;  
options formdlm=' ';
```

```
TITLE "Time Series Analysis of Chinese Wheat Futures Prices  
--- © 2005 Wen Du. All rights Reserved ";
```

```
DATA WHEAT; INFILE 'U:\WT205.DAT';  
  INPUT X;  
  T+1;  
RUN;
```

```
PROC ARIMA ;  
  IDENTIFY VAR=X;  
  IDENTIFY VAR=X(1);
```

```
RUN;
```

```
/*
```

```
TITLE2 "Find an appropriate power transformation for the data";  
%BOXCOXAR(WHEAT, X, AR=6, LAMBDAHI=1.5, LAMBDALO=-0.5, NLAMBDA=21);  
RUN;*/
```

```
DATA TRANS; SET WHEAT;  
  Z=log(X);  
  LZ1=LAG(Z); LZ2=LAG(LZ1); LZ3=LAG(LZ2);  
  LZ4=LAG(LZ3); LZ5=LAG(LZ4); LZ6=LAG(LZ5); LZ7=LAG(LZ6);  
  W=DIF(Z); LW1=LAG(W); LW2=LAG(LW1); LW3=LAG(LW2);  
  LW4=LAG(LW3); LW5=LAG(LW4); LW6=LAG(LW5);
```

```
RUN;
```

```
/*
```

```
PROC REG;  
  MODEL Z = LZ1 LZ2 LZ3 LZ4 LZ5 LZ6 LZ7;  
  OUTPUT OUT=OUT1 R=R;
```

```
RUN;
```

```
PROC ARIMA;  
  IDENTIFY VAR=R;
```

```
RUN;*/
```

```
/*
```

```
PROC REG;  
  MODEL W = LZ1 LW1 LW2 LW3 LW4 LW5 LW6;  
RUN;  
PROC REG;  
  MODEL W = T LZ1 LW1 LW2 LW3 LW4 LW5 LW6;  
RUN;*/
```



```

TITLE2 "AUGMENTED DICKEY-FULLER TEST FOR UNIT ROOT";
%DFTEST(TRANS, Z, AR=6,OUTSTAT=OUT2, TREND=1)
PROC PRINT DATA=OUT2;
RUN;

```

```

%DFTEST(TRANS, Z, AR=6,OUTSTAT=OUT3, TREND=2)
PROC PRINT DATA=OUT3;
RUN;

```

**TITLE2 "Identify an appropriate ARMA model for the transformed data";**

```

PROC ARIMA DATA=TRANS;
  IDENTIFY VAR=Z(1);
  *ESTIMATE P=5 METHOD=ML PLOT;
    *ESTIMATE Q=5 METHOD=ML PLOT;
    ESTIMATE P=0 Q=0 METHOD=ML PLOT NOCONSTANT;
    *ESTIMATE P=6 METHOD=ML PLOT;
    *ESTIMATE Q=6 METHOD=ML PLOT;
    ESTIMATE P=1 METHOD=ML PLOT NOCONSTANT;
    ESTIMATE Q=1 METHOD=ML PLOT NOCONSTANT;
    ESTIMATE P=(5) METHOD=ML PLOT NOCONSTANT;
    FORECAST LEAD=7 OUT=OUTAR5;
    ESTIMATE P=(1,5) METHOD=ML PLOT NOCONSTANT;
    ESTIMATE Q=(5)METHOD=ML PLOT NOCONSTANT;
    FORECAST LEAD=7 OUT=OUTMA5;
    ESTIMATE Q=(1,5) METHOD=ML PLOT NOCONSTANT;
    *ESTIMATE P=5 Q=5 METHOD=ML PLOT;
    ESTIMATE P=1 Q=1 METHOD=ML PLOT NOCONSTANT;
    ESTIMATE P=(5) Q=(5) METHOD=ML PLOT NOCONSTANT;
    ESTIMATE P=(1,5) Q=(1,5) METHOD=ML PLOT NOCONSTANT;
RUN;

```

```

TITLE2 "FORECASTING USING MA((5))";
DATA FAR5;SET OUTAR5;
  IF _N_ LE 287 THEN DELETE;
  FPREDAR5=EXP(FORECAST+STD**2/2);
  KEEP FPREDAR5;
PROC PRINT;

```

```

DATA FMA5;SET OUTMA5;
  IF _N_ LE 287 THEN DELETE;
  FPREDMA5=EXP(FORECAST+STD**2/2);
  KEEP FPREDMA5;
PROC PRINT;
RUN;

```

```
PROC AUTOREG DATA=TRANS;  
MODEL z= / NLAG=5 METHOD=ML BACKSTEP;  
RUN;
```

```
TITLE2 "MODEL FITTING BASED ON CONDITIONAL HETEROSKEDASTICITY";
```

```
TITLE3 "ARCH MODEL FITTING";  
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=1) archtest;  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=2);  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=3 GARCH=(Q=3);  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
TITLE3 "GARCH MODEL FITTING";  
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=1,P=1);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(P=1,Q=2);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL W = / noint GARCH=(P=2,Q=1);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL W = / noint GARCH=(Q=2,P=2);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
quit;
```

#### Appendix E.4. Univariate time series estimation of CBOT Prices (in SAS)

```
options linesize=79 pageno=1 nodate;  
options formdlm=' ';
```

```
TITLE "Time Series Analysis of US Wheat Futures Prices  
--- © 2005 Wen Du. All rights Reserved ";
```

```
DATA WHEAT; INFILE 'D:\AREC\CBOT.DAT';  
INPUT X;  
T+1;  
RUN;
```

```
PROC ARIMA ;  
IDENTIFY VAR=X;  
IDENTIFY VAR=X(1);  
RUN;
```

```
/*  
TITLE2 "Find an appropriate power transformation for the data";  
%BOXCOXAR(WHEAT, X, AR=6, LAMBDAHI=1.5, LAMBDALO=-0.5, NLAMBDA=21);  
RUN;*/
```

```
DATA TRANS; SET WHEAT;  
Z=log(X);  
LZ1=LAG(Z); LZ2=LAG(LZ1); LZ3=LAG(LZ2);  
LZ4=LAG(LZ3); LZ5=LAG(LZ4); LZ6=LAG(LZ5); LZ7=LAG(LZ6);  
W=DIF(Z); LW1=LAG(W); LW2=LAG(LW1); LW3=LAG(LW2);  
LW4=LAG(LW3); LW5=LAG(LW4); LW6=LAG(LW5);  
RUN;
```

```
/*  
PROC REG;  
MODEL Z = LZ1 LZ2 LZ3 LZ4 LZ5 LZ6 LZ7;  
OUTPUT OUT=OUT1 R=R;  
RUN;
```

```
PROC ARIMA;  
IDENTIFY VAR=R;  
RUN;*/
```

```
/*  
PROC REG;  
MODEL W = LZ1 LW1 LW2 LW3 LW4 LW5 LW6;  
RUN;  
PROC REG;  
MODEL W = T LZ1 LW1 LW2 LW3 LW4 LW5 LW6;  
RUN;*/
```

```

TITLE2 "AUGMENTED DICKEY-FULLER TEST FOR UNIT ROOT";
%DFTEST(TRANS, Z, AR=6,OUTSTAT=OUT2, TREND=1)
PROC PRINT DATA=OUT2;
RUN;

```

```

%DFTEST(TRANS, Z, AR=6,OUTSTAT=OUT3, TREND=2)
PROC PRINT DATA=OUT3;
RUN;

```

```

TITLE2 "Identify an appropriate ARMA model for the transformed data";

```

```

PROC ARIMA DATA=TRANS;
  IDENTIFY VAR=Z(1);
  *ESTIMATE P=5 METHOD=ML PLOT;
  *ESTIMATE Q=5 METHOD=ML PLOT;
  ESTIMATE P=0 Q=0 METHOD=ML PLOT NOCONSTANT;
  *ESTIMATE P=6 METHOD=ML PLOT;
  *ESTIMATE Q=6 METHOD=ML PLOT;
  ESTIMATE P=1 METHOD=ML PLOT NOCONSTANT;
  ESTIMATE Q=1 METHOD=ML PLOT NOCONSTANT;
  ESTIMATE P=(5) METHOD=ML PLOT NOCONSTANT;
  FORECAST LEAD=7 OUT=OUTAR5;
  ESTIMATE P=(1,5) METHOD=ML PLOT NOCONSTANT;
  ESTIMATE Q=(5)METHOD=ML PLOT NOCONSTANT;
  FORECAST LEAD=7 OUT=OUTMA5;
  ESTIMATE Q=(1,5) METHOD=ML PLOT NOCONSTANT;
  *ESTIMATE P=5 Q=5 METHOD=ML PLOT;
  ESTIMATE P=1 Q=1 METHOD=ML PLOT NOCONSTANT;
  ESTIMATE P=(5) Q=(5) METHOD=ML PLOT NOCONSTANT;
  ESTIMATE P=(1,5) Q=(1,5) METHOD=ML PLOT NOCONSTANT;
RUN;

```

```

TITLE2 "FORECASTING USING MA((5))";
DATA FAR5;SET OUTAR5;
  IF _N_ LE 287 THEN DELETE;
  FPREDAR5=EXP(FORECAST+STD**2/2);
  KEEP FPREDAR5;
PROC PRINT;

```

```

DATA FMA5;SET OUTMA5;
  IF _N_ LE 287 THEN DELETE;
  FPREDMA5=EXP(FORECAST+STD**2/2);
  KEEP FPREDMA5;
PROC PRINT;
RUN;

```

```
PROC AUTOREG DATA=TRANS;  
MODEL z= / NLAG=5 METHOD=ML BACKSTEP;  
RUN;
```

```
TITLE2 "MODEL FITTING BASED ON CONDITIONAL HETEROSKEDASTICITY";
```

```
TITLE3 "ARCH MODEL FITTING";  
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=1) archtest;  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=2);  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=3 GARCH=(Q=3);  
output out=outarch lcl=low predicted=pred;  
RUN;
```

```
TITLE3 "GARCH MODEL FITTING";  
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(Q=1,P=1);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL X = / NLAG=1 GARCH=(P=1,Q=2);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL W = / noint GARCH=(P=2,Q=1);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
PROC AUTOREG DATA=TRANS;  
MODEL W = / noint GARCH=(Q=2,P=2);  
output out=outgarch lcl=low predicted=pred;  
RUN;
```

```
quit;
```

## Appendix E.5. Cointegration test (in SAS)

```
options linesize=79 pageno=1 nodate;  
options formdlm=' ';
```

```
TITLE "Time-series analysis: Cointegration test of wheat futures prices: CZCE vs. CBOT  
--- © 2005 Wen Du. All rights Reserved.";
```

```
data wcoint;  
input CBOT CZCE;  
cards;
```

843.9557	1193
853.0795	1174
849.2779	1173
860.6827	1158
866.7653	1153
881.9717	1161
897.1781	1147
901.7400	1145
898.6987	1133
904.0210	1114
902.5003	1133
897.1781	1138
904.7813	1150
900.2194	1152
886.5336	1108
898.6987	1084
888.0542	1088
876.6494	1076
882.7320	1064
879.6907	1059
918.4671	1038
907.0622	1050
906.3019	1053
897.1781	1065
906.3019	1057
897.1781	1060
874.3685	1057
878.9304	1057
851.5589	1061
843.9557	1073
853.0795	1058
854.6001	1057
851.5589	1056
851.5589	1055
856.8811	1055
856.8811	1075
862.2033	1070
867.5256	1060
858.4017	1060
866.7653	1062
890.3352	1060
884.2526	1062
876.6494	1069

894.8971	1069
877.4097	1066
861.4430	1064
866.0049	1064
849.2779	1061
838.6334	1060
842.4350	1062
827.2286	1061
834.0715	1058
846.2366	1055
866.7653	1072
853.8398	1057
848.5176	1059
849.2779	1058
841.6747	1057
856.1208	1056
838.6334	1056
839.3937	1058
848.5176	1059
855.3605	1057
847.7573	1063
842.4350	1063
837.1128	1061
841.6747	1058
836.3524	1058
836.3524	1063
841.6747	1062
829.5096	1061
809.7412	1061
810.5016	1064
851.5589	1060
850.0382	1065
869.8065	1070
891.0955	1075
897.9384	1076
892.6162	1088
887.2939	1090
878.1701	1088
861.4430	1091
874.3685	1090
887.2939	1092
890.3352	1088
885.7733	1090
885.7733	1100
889.5749	1100
869.8065	1099
872.0875	1094
859.1621	1097
862.2033	1103
846.2366	1097
850.0382	1100
840.1540	1098
847.7573	1094
859.1621	1097
843.9557	1090
841.6747	1090

831.0302	1097
837.1128	1098
837.1128	1096
852.3192	1092
868.2859	1091
878.1701	1100
881.2114	1090
865.2446	1089
871.3272	1087
867.5256	1087
864.4843	1093
866.0049	1094
824.9476	1090
783.1300	1091
786.9316	1089
775.5268	1137
774.7665	1090
781.6094	1096
779.3284	1099
767.9236	1095
774.0062	1104
756.5188	1100
742.8330	1107
733.7092	1100
743.5934	1100
750.4362	1100
751.9569	1099
746.6346	1099
746.6346	1099
742.8330	1099
747.3950	1099
754.2378	1099
748.9156	1092
745.1140	1101
748.9156	1107
736.7505	1108
720.7837	1108
710.1393	1108
719.2631	1100
716.2218	1105
716.9821	1097
720.0234	1095
725.3457	1100
731.4282	1097
740.5521	1100
728.3869	1097
726.1060	1098
718.5028	1101
713.9409	1101
710.8996	1095
729.9076	1095
734.4695	1095
737.5108	1108
761.0807	1092
748.9156	1099
762.6014	1096



761.0807	1096
769.4443	1096
752.7172	1096
758.7998	1096
761.8410	1096
758.0394	1096
745.1140	1096
735.9902	1096
735.9902	1096
903.2606	1096
914.6654	1096
893.3765	1096
896.4178	1096
889.5749	1096
899.4590	1539
908.5829	1531
910.8638	1527
921.5083	1535
923.0290	1536
936.7147	1533
945.8386	1549
970.1688	1550
971.6895	1535
968.6482	1497
945.8386	1472
958.0037	1467
948.8799	1464
936.7147	1452
927.5909	1454
929.1115	1453
916.9464	1447
918.4671	1427
912.3845	1424
916.9464	1426
924.5496	1421
913.9051	1421
914.6654	1423
913.1448	1427
924.5496	1428
941.2767	1427
939.7560	1429
937.4751	1424
945.8386	1413
927.5909	1418
924.5496	1402
929.8719	1403
923.0290	1408
916.9464	1406
921.5083	1415
925.3099	1418
924.5496	1419
921.5083	1420
929.1115	1417
938.2354	1412
929.1115	1432
923.0290	1430

913.9051	1440
923.7893	1433
933.6735	1431
938.9957	1437
933.6735	1426
935.1941	1434
916.9464	1440
922.2687	1442
918.4671	1450
916.1861	1452
916.1861	1449
909.3432	1449
902.5003	1450
910.8638	1446
923.0290	1444
916.9464	1442
923.0290	1446
931.3925	1443
928.3512	1443
920.7480	1432
919.9877	1424
943.5576	1425
934.4338	1428
954.9624	1422
959.5244	1423
958.0037	1421
954.9624	1409
961.8053	1414
973.9704	1414
973.9704	1410
975.4911	1408
963.3260	1410
957.2434	1410
963.3260	1396
964.8466	1405
919.9877	1400
912.3845	1390
916.1861	1365
913.9051	1361
912.3845	1357
899.4590	1339
903.2606	1341
914.6654	1349
913.9051	1351
909.3432	1353
909.3432	1361
898.6987	1352
888.8146	1348
888.0542	1342
886.5336	1318
883.4923	1318
904.7813	1335
904.0210	1333
912.3845	1339
924.5496	1343
921.5083	1349

913.9051	1350
915.4258	1349
914.6654	1345
932.1528	1338
931.3925	1340
924.5496	1330
897.1781	1328
884.2526	1343
879.6907	1348
888.0542	1349
876.6494	1359
856.1208	1373
862.2033	1366
877.4097	1366
875.8891	1366
868.2859	1364
870.5669	1361
843.1953	1363
853.0795	1353
863.7240	1327
870.5669	1319
869.8065	1310
863.7240	1310
856.1208	1296
848.5176	1297
859.1621	1300
878.1701	1302
887.2939	1298
872.0875	1298
881.2114	1286
877.4097	1285
875.8891	1289
867.5256	1299
866.7653	1296
881.9717	1291
887.2939	1309
872.0875	1305
892.6162	1303
846.2366	1302
840.9144	1297
849.2779	1286
855.3605	1272
878.1701	1268
873.6081	1271
868.2859	1275
869.8065	1264
857.6414	1264
831.7905	1238
821.9064	1227
821.9064	1230
826.4683	1228
820.3857	1230
835.5921	1206
833.3112	1199
842.4350	1197
853.8398	1202

834.0715	1215
824.1873	1212
825.7080	1205
837.1128	1233
835.5921	1230
830.2699	1233
834.0715	1227
831.0302	1234
823.4270	1233
812.0222	1234
833.3112	1239
829.5096	1247
810.5016	1243
810.5016	1231
798.3364	1215
780.0887	1208
788.4523	1204
785.4110	1206
774.0062	1212
784.6507	1209
793.7745	1228
801.3777	1215
811.2619	1219
816.5841	1211
815.0635	1216
824.1873	1216
829.5096	1217
879.6907	1213
871.3272	1213
857.6414	1210
881.9717	1211
878.1701	1205
878.9304	1204
861.4430	1199
862.2033	1196
859.1621	1198
859.1621	1193
854.6001	1185
852.3192	1181
842.4350	1173
846.9969	1154
834.8318	1150
819.6254	1153
805.1793	1154
805.9396	1156
812.0222	1153
816.5841	1155
824.1873	1153
821.9064	1155
825.7080	1164
817.3444	1161
810.5016	1161
812.0222	1162
812.7825	1164
809.7412	1159
815.0635	1160

821.9064	1163
843.1953	1159
834.0715	1158
831.7905	1145
819.6254	1130
836.3524	1126
825.7080	1122
845.4763	1105
840.9144	1093
835.5921	1093
822.6667	1095
818.8651	1116
824.1873	1096
834.8318	1074
812.0222	1074
916.9464	1084
901.7400	1063
892.6162	1083
901.7400	1079
901.7400	1240
907.8226	1233
909.3432	1238
901.7400	1236
898.6987	1237
890.3352	1237
878.9304	1232
875.8891	1229
881.9717	1229
883.4923	1228
881.9717	1228
878.9304	1225
885.0130	1232
891.0955	1210
895.6574	1208
907.8226	1211
901.7400	1216
907.8226	1231
906.3019	1234
919.9877	1233
938.2354	1241
926.0703	1259
932.1528	1261
929.1115	1253
921.5083	1246
916.9464	1250
919.9877	1236
923.0290	1226
930.6322	1201
921.5083	1191
921.5083	1209
913.9051	1220
901.7400	1217
910.8638	1217
910.8638	1218
919.9877	1193
923.0290	1200

918.4671	1192
921.5083	1185
919.9877	1171
894.1368	1153
892.6162	1157
883.4923	1152
881.9717	1162
903.2606	1166
894.1368	1177
891.0955	1166
891.0955	1167
885.0130	1174
883.4923	1159
886.5336	1147
885.0130	1148
874.3685	1151
885.0130	1153
883.4923	1163
883.4923	1163
889.5749	1164
875.8891	1159
875.8891	1153
866.7653	1156
878.1701	1151
876.6494	1155
910.8638	1179
907.8226	1188
905.5416	1177
906.3019	1184
924.5496	1184
930.6322	1185
923.7893	1176
924.5496	1179
923.7893	1177
918.4671	1166
912.3845	1153
917.7067	1148
921.5083	1152
929.1115	1150
907.8226	1151
906.3019	1151
902.5003	1145
904.0210	1151
909.3432	1155
897.1781	1153
898.6987	1152
891.0955	1151
894.1368	1152
895.6574	1147
883.4923	1143
889.5749	1145
885.0130	1150
888.0542	1151
878.9304	1155
874.3685	1154
873.6081	1153

868.2859	1152
879.6907	1146
877.4097	1146
890.3352	1146
890.3352	1148
882.7320	1156
878.1701	1154
868.2859	1159
875.8891	1157
870.5669	1157
877.4097	1156
883.4923	1160
875.8891	1163
880.4510	1161
871.3272	1158
882.7320	1157
881.2114	1159
883.4923	1158
894.8971	1160
912.3845	1163
894.8971	1164
896.4178	1165
894.8971	1169
895.6574	1168
886.5336	1168
878.9304	1166
867.5256	1164
859.1621	1167
866.7653	1165
861.4430	1158
866.0049	1152
866.0049	1152
877.4097	1152
878.1701	1153
859.1621	1155
855.3605	1155
850.7985	1156
850.0382	1155
843.9557	1154
837.1128	1155
829.5096	1145
827.2286	1137
837.8731	1131
846.2366	1131
846.9969	1133
843.9557	1133
863.7240	1137
862.9637	1140
875.1288	1136
855.3605	1136
847.7573	1132
856.8811	1134
846.9969	1141
836.3524	1146
842.4350	1149
835.5921	1148

844.7160	1146
859.9224	1150
859.9224	1149
877.4097	1155
891.8558	1153
878.9304	1159
881.9717	1160
875.1288	1166
862.2033	1171
871.3272	1177
872.8478	1179
886.5336	1183
919.9877	1179
914.6654	1177
900.9797	1179
899.4590	1183
906.3019	1184
907.8226	1179
897.9384	1189
911.6242	1189
911.6242	1195
915.4258	1197
954.9624	1192
951.9211	1193
980.8133	1196
974.7308	1195
979.2927	1194
981.5736	1186
964.0863	1189
974.7308	1189
987.6562	1181
983.0943	1178
967.8879	1177
984.6149	1179
1015.7881	1179
1018.8293	1177
1013.5071	1179
1005.9039	1181
1033.2754	1185
1011.9865	1187
1021.8706	1181
1018.8293	1182
1018.8293	1185
992.9784	1184
991.4578	1175
1015.7881	1169
1018.0690	1171
1024.9119	1167
1027.9532	1168
1039.3580	1171
1053.0438	1169
1029.4738	1169
1047.7215	1169
1069.7708	1170
1084.9772	1169
1085.7375	1171



```

1065.9692 1174
1057.6057 1178
1062.1676 1175
1030.2341 1175
1028.7135 1176
1034.7961 1177
1057.6057 1170
1075.0931 1165
1072.0518 1162
1080.4153 1160
1080.4153 1159
1101.7043 1165
1116.1504 1155
1152.6457 1155
1175.4553 1165
1227.1571 1166
1262.1319 1166
1259.0906 1168
1265.1732 1168
1243.8842 1168
1201.3062 1162;

```

```
/*
```

```
proc print;
run;*/
```

```
proc statespace;
var czce cbot;
run;
```

```
DATA ALL; SET WCOINT;
  LZ=LAG(CZCE); LB=LAG(CBOT);
  WZ=CZCE-LZ; WB=CBOT-LB;
  L2Z=LAG(WZ); L2B=LAG(WB);
  L3Z=LAG(L2Z); L3B=LAG(L2B);
  L4Z=LAG(L3Z); L4B=LAG(L3B);
  L5Z=LAG(L4Z); L5B=LAG(L4B);
  L6Z=LAG(L5Z); L6B=LAG(L5B);
  L7Z=LAG(L6Z); L7B=LAG(L6B);
  L8Z=LAG(L7Z); L8B=LAG(L7B);
  L9Z=LAG(L8Z); L9B=LAG(L8B);
  L10Z=LAG(L9Z); L10B=LAG(L9B);
```

```
RUN;
```

```
TITLE2 "AR ORDER P=1";
PROC CANCORR SHORT;
  VAR WZ WB;
  WITH LZ LB;
RUN;
```

```
/*Canonical correlations for the AR order*/
```

```
TITLE2 "AR ORDER P=2";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L2Z L2B;
    PARTIAL LZ LB;
RUN;
```

```
TITLE2 "AR ORDER P=3";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L3Z L3B;
    PARTIAL LZ LB L2Z L2B;
RUN;
```

```
TITLE2 "AR ORDER P=4";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L4Z L4B;
    PARTIAL LZ LB L2Z L2B L3Z L3B;
RUN;
```

```
TITLE2 "AR ORDER P=5";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L5Z L5B;
    PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B;
RUN;
```

```
TITLE2 "AR ORDER P=6";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L6Z L6B;
    PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B L5Z L5B;
RUN;
```

```
TITLE2 "AR ORDER P=7";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L7Z L7B;
    PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B L5Z L5B L6Z L6B;
RUN;
```

```
TITLE2 "AR ORDER P=8";
PROC CANCELL SHORT;
  VAR WZ WB;
    WITH L8Z L8B;
```

```

PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B L5Z L5B L6Z L6B L7Z L7B;
RUN;

TITLE2 "AR ORDER P=9";
PROC CANCORR SHORT;
VAR WZ WB;
WITH L9Z L9B;
PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B L5Z L5B L6Z L6B L7Z L7B L8Z L8B;
RUN;

TITLE2 "AR ORDER P=10";
PROC CANCORR SHORT;
VAR WZ WB;
WITH L10Z L10B;
PARTIAL LZ LB L2Z L2B L3Z L3B L4Z L4B L5Z L5B L6Z L6B L7Z L7B L8Z L8B
L9Z L9B;
RUN;

TITLE2 "COINTEGRATION TEST";
proc varmax data=wcoint;
model czce cbot / p=6 dfctest cointtest=(johansen=(normalize=czce));
run;

TITLE2 "Augmented Dickey-Fuller Unit Root Test for CZCE Sept. Prices";
%DFTEST(WCOINT,CZCE, AR=6, OUTSTAT=OUTZ0, TREND=0);
%DFTEST(WCOINT,CZCE, AR=6, OUTSTAT=OUTZ1, TREND=1);
%DFTEST(WCOINT,CZCE, AR=6, OUTSTAT=OUTZ2, TREND=2);
PROC PRINT DATA=OUTZ0;
PROC PRINT DATA=OUTZ1;
PROC PRINT DATA=OUTZ2;
RUN;

TITLE2 "Augmented Dickey-Fuller Unit Root Test for CBOT Sept. Prices";
%DFTEST(WCOINT,CBOT, AR=6, OUTSTAT=OUTB0, TREND=0);
%DFTEST(WCOINT,CBOT, AR=6, OUTSTAT=OUTB1, TREND=1);
%DFTEST(WCOINT,CBOT, AR=6, OUTSTAT=OUTB2, TREND=2);
PROC PRINT DATA=OUTB0;
PROC PRINT DATA=OUTB1;
PROC PRINT DATA=OUTB2;
RUN;

quit;

```

## Appendix E.6. Nonsynchronicity Test (in SAS)

```
options linesize=79 pageno=1 nodate;  
options formdlm=' ';
```

```
TITLE "Time-series analysis: nonsynchronicity test of wheat futures prices: CZCE vs. CBOT  
--- © 2005 Wen Du. All rights Reserved.";
```

```
DATA FIRSTDIF;  
    INPUT CBWX CZWX;  
    T=_n_;
```

```
CARDS;  
3      -19  
-1.25  -1  
3.75   -15  
2      -5  
5       8  
5     -14  
1.5    -2  
-1     -12  
1.75   -19  
-0.5   19  
-1.75  5  
2.5    12  
-1.5   2  
-4.5   -44  
4      -24  
-3.5   4  
-3.75  -12  
2      -12  
-1     -5  
12.75  -21  
-3.75  12  
-0.25  3  
-3     12  
3      -8  
-3     3  
-7.5   -3  
1.5    0  
-9     4  
-2.5   12  
3      -15  
0.5    -1  
-1     -1  
0      -1  
1.75   0  
0      20  
1.75   -5  
1.75  -10  
-3     0  
2.75   2  
7.75  -2
```

-2 2  
-2.5 7  
6 0  
-5.75 -3  
-5.25 -2  
1.5 0  
-5.5 -3  
-3.5 -1  
1.25 2  
-5 -1  
2.25 -3  
4 -3  
6.75 17  
-4.25 -15  
-1.75 2  
0.25 -1  
-2.5 -1  
4.75 -1  
-5.75 0  
0.25 2  
3 1  
2.25 -2  
-2.5 6  
-1.75 0  
-1.75 -2  
1.5 -3  
-1.75 0  
0 5  
1.75 -1  
-4 -1  
-6.5 0  
0.25 3  
13.5 -4  
-0.5 5  
6.5 5  
7 5  
2.25 1  
-1.75 12  
-1.75 2  
-3 -2  
-5.5 3  
4.25 -1  
4.25 2  
1 -4  
-1.5 2  
0 10  
1.25 0  
-6.5 -1  
0.75 -5  
-4.25 3  
1 6  
-5.25 -6  
1.25 3  
-3.25 -2  
2.5 -4  
3.75 3

-5	-7	
-0.75	0	
-3.5	7	
2	1	
0	-2	
5	-4	
5.25	-1	
3.25	9	
1	-10	
-5.25	-1	
2	-2	
-1.25	0	
-1	6	
0.5	1	
-13.5	-4	
-13.75		1
1.25	-2	
-3.75	48	
-0.25	-47	
2.25	6	
-0.75	3	
-3.75	-4	
2	9	
-5.75	-4	
-4.5	7	
-3	-7	
3.25	0	
2.25	0	
0.5	-1	
-1.75	0	
0	0	
-1.25	0	
1.5	0	
2.25	0	
-1.75	-7	
-1.25	9	
1.25	6	
-4	1	
-5.25	0	
-3.5	0	
3	-8	
-1	5	
0.25	-8	
1	-2	
1.75	5	
2	-3	
3	3	
-4	-3	
-0.75	1	
-2.5	3	
-1.5	0	
-1	-6	
6.25	0	
1.5	0	
1	13	
7.75	-16	

-4	7
4.5	-3
-0.5	0
2.75	0
-5.5	0
2	0
1	0
-1.25	0
-4.25	0
-3	0
0	0
55	0
3.75	0
-7	0
1	0
-2.25	0
3.25	443
3	-8
0.75	-4
3.5	8
0.5	1
4.5	-3
3	16
8	1
0.5	-15
-1	-38
-7.5	-25
4	-5
-3	-3
-4	-12
-3	2
0.5	-1
-4	-6
0.5	-20
-2	-3
1.5	2
2.5	-5
-3.5	0
0.25	2
-0.5	4
3.75	1
5.5	-1
-0.5	2
-0.75	-5
2.75	-11
-6	5
-1	-16
1.75	1
-2.25	5
-2	-2
1.5	9
1.25	3
-0.25	1
-1	1
2.5	-3
3	-5

-3	20	
-2	-2	
-3	10	
3.25	-7	
3.25	-2	
1.75	6	
-1.75	-11	
0.5	8	
-6	6	
1.75	2	
-1.25	8	
-0.75	2	
0	-3	
-2.25	0	
-2.25	1	
2.75	-4	
4	-2	
-2	-2	
2	4	
2.75	-3	
-1	0	
-2.5	-11	
-0.25	-8	
7.75	1	
-3	3	
6.75	-6	
1.5	1	
-0.5	-2	
-1	-12	
2.25	5	
4	0	
0	-4	
0.5	-2	
-4	2	
-2	0	
2	-14	
0.5	9	
-14.75		-5
-2.5	-10	
1.25	-25	
-0.75	-4	
-0.5	-4	
-4.25	-18	
1.25	2	
3.75	8	
-0.25	2	
-1.5	2	
0	8	
-3.5	-9	
-3.25	-4	
-0.25	-6	
-0.5	-24	
-1	0	
7	17	
-0.25	-2	
2.75	6	



4	4	
-1	6	
-2.5	1	
0.5	-1	
-0.25	-4	
5.75	-7	
-0.25	2	
-2.25	-10	
-9	-2	
-4.25	15	
-1.5	5	
2.75	1	
-3.75	10	
-6.75	14	
2	-7	
5	0	
-0.5	0	
-2.5	-2	
0.75	-3	
-9	2	
3.25	-10	
3.5	-26	
2.25	-8	
-0.25	-9	
-2	0	
-2.5	-14	
-2.5	1	
3.5	3	
6.25	2	
3	-4	
-5	0	
3	-12	
-1.25	-1	
-0.5	4	
-2.75	10	
-0.25	-3	
5	-5	
1.75	18	
-5	-4	
6.75	-2	
-15.25		-1
-1.75	-5	
2.75	-11	
2	-14	
7.5	-4	
-1.5	3	
-1.75	4	
0.5	-11	
-4	0	
-8.5	-26	
-3.25	-11	
0	3	
1.5	-2	
-2	2	
5	-24	
-0.75	-7	

3 -2  
3.75 5  
-6.5 13  
-3.25 -3  
0.5 -7  
3.75 28  
-0.5 -3  
-1.75 3  
1.25 -6  
-1 7  
-2.5 -1  
-3.75 1  
7 5  
-1.25 8  
-6.25 -4  
0 -12  
-4 -16  
-6 -7  
2.75 -4  
-1 2  
-3.75 6  
3.5 -3  
3 19  
2.5 -13  
3.25 4  
1.75 -8  
-0.5 5  
3 0  
1.75 1  
16.5 -4  
-2.75 0  
-4.5 -3  
8 1  
-1.25 -6  
0.25 -1  
-5.75 -5  
0.25 -3  
-1 2  
0 -5  
-1.5 -8  
-0.75 -4  
-3.25 -8  
1.5 -19  
-4 -4  
-5 3  
-4.75 1  
0.25 2  
2 -3  
1.5 2  
2.5 -2  
-0.75 2  
1.25 9  
-2.75 -3  
-2.25 0  
0.5 1  
0.25 2

-1	-5
1.75	1
2.25	3
7	-4
-3	-1
-0.75	-13
-4	-15
5.5	-4
-3.5	-4
6.5	-17
-1.5	-12
-1.75	0
-4.25	2
-1.25	21
1.75	-20
3.5	-22
-7.5	0
34.5	10
-5	-21
-3	20
3	-4
0	161
2	-7
0.5	5
-2.5	-2
-1	1
-2.75	0
-3.75	-5
-1	-3
2	0
0.5	-1
-0.5	0
-1	-3
2	7
2	-22
1.5	-2
4	3
-2	5
2	15
-0.5	3
4.5	-1
6	8
-4	18
2	2
-1	-8
-2.5	-7
-1.5	4
1	-14
1	-10
2.5	-25
-3	-10
0	18
-2.5	11
-4	-3
3	0
0	1

3	-25
1	7
-1.5	-8
1	-7
-0.5	-14
-8.5	-18
-0.5	4
-3	-5
-0.5	10
7	4
-3	11
-1	-11
0	1
-2	7
-0.5	-15
1	-12
-0.5	1
-3.5	3
3.5	2
-0.5	10
0	0
2	1
-4.5	-5
0	-6
-3	3
3.75	-5
-0.5	4
11.25	24
-1	9
-0.75	-11
0.25	7
6	0
2	1
-2.25	-9
0.25	3
-0.25	-2
-1.75	-11
-2	-13
1.75	-5
1.25	4
2.5	-2
-7	1
-0.5	0
-1.25	-6
0.5	6
1.75	4
-4	-2
0.5	-1
-2.5	-1
1	1
0.5	-5
-4	-4
2	2
-1.5	5
1	1
-3	4

-1.5 -1  
-0.25 -1  
-1.75 -1  
3.75 -6  
-0.75 0  
4.25 0  
0 2  
-2.5 8  
-1.5 -2  
-3.25 5  
2.5 -2  
-1.75 0  
2.25 -1  
2 4  
-2.5 3  
1.5 -2  
-3 -3  
3.75 -1  
-0.5 2  
0.75 -1  
3.75 2  
5.75 3  
-5.75 1  
0.5 1  
-0.5 4  
0.25 -1  
-3 0  
-2.5 -2  
-3.75 -2  
-2.75 3  
2.5 -2  
-1.75 -7  
1.5 -6  
0 0  
3.75 0  
0.25 1  
-6.25 2  
-1.25 0  
-1.5 1  
-0.25 -1  
-2 -1  
-2.25 1  
-2.5 -10  
-0.75 -8  
3.5 -6  
2.75 0  
0.25 2  
-1 0  
6.5 4  
-0.25 3  
4 -4  
-6.5 0  
-2.5 -4  
3 2  
-3.25 7  
-3.5 5

2	3
-2.25	-1
3	-2
5	4
0	-1
5.75	6
4.75	-2
-4.25	6
1	1
-2.25	6
-4.25	5
3	6
0.5	2
4.5	4
11	-4
-1.75	-2
-4.5	2
-0.5	4
2.25	1
0.5	-5
-3.25	10
4.5	0
0	6
1.25	2
13	-5
-1	1
9.5	3
-2	-1
1.5	-1
0.75	-8
-5.75	3
3.5	0
4.25	-8
-1.5	-3
-5	-1
5.5	2
10.25	0
1	-2
-1.75	2
-2.5	2
9	4
-7	2
3.25	-6
-1	1
0	3
-8.5	-1
-0.5	-9
8	-6
0.75	2
2.25	-4
1	1
3.75	3
4.5	-2
-7.75	0
6	0
7.25	1





























```

output out=r;
run;

title2 "CZCE of CBOT MA(1)-xlag=1";
proc varmax data=combine;
model czwx = cbwxlag1 czsd / method = ml;
output out=r;
run;

title2 "CZCE of CBOT MA(1)-xlag=2";
proc varmax data=combine;
model czwx = cbwx cbwxlag1 czsd / method = ml;
output out=r;
run;

title2 "CZCE of CBOT AR(1)-xlag=0";
proc varmax data=combine;
model czwx cbwx = czsd cbsd / method = ml p=0;
output out=r;
run;

title2 "CZCE of CBOT AR(1)-xlag=1";
proc varmax data=combine;
model czwx cbwx = czsd cbsd / method = ml p=1;
output out=r;
run;

```

## Appendix E.7. Multivariate ARCH/GARCH Estimation (in S-PLUS)

```
# Multivariate GARCH analysis of CBOT and CZCE wheat futures prices, both in Yuan/Ton

# import cbot_czce first difference price data (623*2)
# and switching dummy variables (623*2), first 1 for CBOT and rest 1 for CZCE,
# using "scan" command

bi.dif.con <- matrix(scan(file="d:\\arec\\date_adjusted_converted_dif.txt"), ncol=2, byrow=623)
bi.sd.2nd <- matrix(scan(file="d:\\arec\\date_adjusted_sd_2nd.txt"), ncol=2, byrow=623)

# bivariate garch analysis, using "mgarch" command and diagonal-vec model (~dvec())
# for the possible correlation between the two variances

# ARCH model fitting

bi.arch1.con <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(1,0), control=bhhh.control(n.iter=50000))
# convergence reached at n=15068

# GARCH model fitting, using diagonal-vec model

bi.garch11.con <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(1,1), control=bhhh.control(n.iter=10000))
bi.garch21.con <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(2,1), control=bhhh.control(n.iter=10000))
bi.garch22.con <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(2,2), control=bhhh.control(n.iter=10000))

# although garch(2,1), garch(2,2) convergent, estimation yields "NA" for estimated
# parameters

summary(bi.arch1.con)
summary(bi.garch11.con)

compare(bi.arch1.con,bi.garch11.con)

# higher order ARCH/GARCH models are not convergent

# ARCH model fitting, assuming "t" distribution, using ~dvec()

bi.arch1.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(1,0), cond.dist="t",
  control=bhhh.control(n.iter=10000))
bi.arch2.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(2,0), cond.dist="t",
  control=bhhh.control(n.iter=10000))
```

```

# GARCH model fitting, assuming "t" distribution, using ~dvec()

bi.garch11.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~dvec(1,1), cond.dist="t",
  control=bhhh.control(n.iter=10000))
bi.garch21.con.t <- mgarch(bi.dif~bi.sd.2nd, ~dvec(2,1), cond.dist="t",
  control=bhhh.control(n.iter=10000))

# higher order ARCH/GARCH models not convergent under "t" distribution

summary(bi.arch1.con.t)
summary(bi.garch11.con.t)

compare(bi.arch1.con.t, bi.garch11.con.t)

#####
# In DVEC form, GARCH(1,1) has the best fit under both normal and t distributions      #
#####

# bivariate garch analysis, using "mgarch" command and CCC model (~ccc())
# for the possible correlation between the two variances

# ARCH model fitting

bi.arch1.ccc.con <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(1,0), control=bhhh.control(n.iter=10000))
summary(bi.arch1.ccc.con)

# GARCH model fitting

bi.garch11.ccc.con <- mgarch(bi.dif.con~bi.sd.2nd, ~ccc(1,1), cccor.choice=1,
  control=bhhh.control(n.iter=5000))
summary(bi.garch11.ccc.con)

# higher order ARCH/GARCH models not convergent

# assuming "t" distribution, bivariate garch analysis

# ARCH model fitting
bi.arch1.ccc.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~ccc(1,0), cccor.choice=1, cond.dist="t",

```

```

    control=bhhh.control(n.iter=5000))
summary(bi.arch1.ccc.con.t)

# higher order ARCH/GARCH models not convergent under "t" distribution

compare(bi.arch1.ccc.con, bi.garch11.ccc.con)

# GARCH model fitting
bi.garch11.ccc.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~ccc(1,1), cccor.choice=1, cond.dist="t",
    control=bhhh.control(n.iter=5000))
bi.arch2.full.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(2,0), cond.dist="t",
    control=bhhh.control(n.iter=5000))
summary(bi.garch11.ccc.con.t)

compare(bi.arch1.ccc.con.t, bi.garch11.ccc.con.t)

# higher order models not convergent

summary(bi.arch1.ccc.con)
summary(bi.garch11.ccc.con)
compare(bi.arch1.ccc.con, bi.garch11.ccc.con)

summary(bi.arch1.ccc.con.t)
summary(bi.garch11.ccc.con.t)
compare(bi.arch1.ccc.con.t, bi.garch11.ccc.con.t)

#####
# In CCC form, GARCH(1,1) has the best fit under both normal and t distributions      #
#####

# bivariate garch analysis, using "mgarch" command and FULL model (~bekk())
# for the possible correlation between the two variances

# ARCH model fitting

bi.arch1.full.con <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(1,0), control=bhhh.control(n.iter=5000))
bi.arch2.full.con <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(2,0), control=bhhh.control(n.iter=5000))
bi.arch3.full.con <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(3,0), control=bhhh.control(n.iter=5000))

# GARCH model fitting
# no workable garch models under the full model

```

```

# assuming "t" distribution, bivariate garch analysis

# ARCH model fitting

bi.arch1.full.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(1,0), cond.dist="t",
  control=bhhh.control(n.iter=5000))
bi.arch2.full.con.t <- mgarch(bi.dif.con~bi.sd.2nd, ~bekk(2,0), cond.dist="t",
  control=bhhh.control(n.iter=5000))

summary(bi.arch1.full.con)
summary(bi.arch1.full.con.t)

compare(bi.arch1.full.con, bi.arch1.full.con.t)

# GARCH model fitting
# no workable garch models under the full model

#####
# In BEKK form, ARCH(1) has the best fit under both normal and t distributions      #
#####

```