Speculation and Price Volatility: The Case of Rice in United States

by

Ali Doroudian

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Abstract

In response to the rampant and high volatility in rice prices relative to other grains over the past few decades and calls by governments for tighter control and regulation on futures trading to limit speculation and curtail volatility, this work evaluates the performance of the rice futures market in United State in terms of its impact on the nation's rice cash price volatility.

This study presents a refined form of Milton Friedman's original theory (1953) that speculation leads to less volatility unless it is carried out by irrational speculators. It will test this theory empirically using time series econometrics.

Generalized autoregressive conditional heteroskedasticity (GARCH) is used to measure volatility of the price of rice. Vector autoregressive (VAR) models are deployed to measure the impact of trading activity on cash price volatility through Granger Causality test, forecast error variance decomposition (FEVD), and impulse response (IR) methods.

Results show that rice cash price volatility after the introduction of the rice futures market on the Chicago Board of Trade is lowered by 51%**.** The Granger Causality test also indicates that sudden changes in the futures market trading activity (proxy for the presence of irrational speculators) cause higher volatility in the cash market. The FEVD, and IR methods indicate that a sudden rise in non-commercial open interest has a larger impact on cash price volatility than changes in trading volume.

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Dedication

This Work is dedicated to

Dr. Ahmad Doroudian

Chapter 1: Introduction and Objectives

Planting rice in never fun;
Bent from morn till set of sun;
Cannot stand and cannot sit;
Cannot rest for a little bit.
Oh, my back is like to break;
Oh, my bones with dampness ache;
And my legs are numb and set
From the soaking in the wet (Fowke & Glazer, 1973) a Filipino song

1.1 Introduction

Food prices have increased and become significantly more volatile during the past few years. Periods of rapid price increase have been followed by precipitous decline in prices. What separates the current period of high volatility in food prices from others in recent history is its persistence. This lingering high volatility in staple foods and agricultural commodity prices is particularly disastrous for the poor, who must rely on very few affordable sources of food for survival of which rice is one.

Rice is a staple food for more than half of the world's population, mainly in East and South East Asia. Relative to other grains, rice requires very little processing to reach consumption stage. Also unlike other grains, it is produced only for human consumption. These characteristics along with its high calorie content make it a valuable source of food for the poor. The price of rice has not been immune to the high rampant volatility in food prices over the past few years. The unprecedented high volatility in rice prices jeopardized the lives of millions and led to short term political and social unrest in some countries that depend on the grain as a major source of food. Therefore, understanding the sources of price volatility and seeking ways to avoid or navigate through it is important in ensuring food security and stability.

The thinness in rice trade and geographical concentration of its production has always been a cause for concern about the supply of rice. In order to secure supplies and stabilize domestic prices, the governments of many rice dependent countries have emergency policies in place that could stop trade and lead to high volatility in global rice prices in a very short period of time. Therefore other tools should be developed and promoted to prevent such price volatility in the rice market. The futures market could be one such tool, and by evaluating the rice futures market's impact on cash price volatility some light could be shed on whether rice futures market could be used to stabilize cash prices.

Several reasons have been put forward to explain the recent rise in food prices and high volatility. Amongst these is the rapid economic growth that developing economies have experienced over the past few decades. Economic growth in these economies has increased global demand for meat. As a result a significant amount of land that could be used for grain production is now used for livestock. This certainly puts constraint on supplies of grains and basic food items. Another reason cited for high price volatility is inconsistency of supplies caused by climate change. Recent droughts, floods, and other unusual weather patterns have disrupted the flow of grains and other agricultural products around the globe. Lastly, speculation has been widely blamed for the high volatility in food prices.

The food market has attracted a relatively large sum of investment over the past several years. Most of this investment has been placed by entities that do not plan to be involved in any part of the food supply chain. Instead their objective has been to speculate on food prices. These entities are referred to as the non-commercial interest in the market. Their activities have come under great scrutiny by both the academic and political establishment.

Speculation and its impact on price volatility has been a subject of many studies. However it seems that a clear answer as to whether speculation stabilizes or destabilizes prices in the market for a commodity has not yet been provided. Most studies acknowledge this and instead focus on presenting conditions under which speculation can lead to higher or lower volatility.

Almost all the speculation by non-commercial interest on food prices is carried out through futures markets. Agricultural commodities are widely traded on futures markets around the world. Futures contracts are a hedging tool for participants and traders in the physical commodity market (commercial interest)[1]. However, recently more than ever before futures contracts have become prominent tools for speculation in the commodities market by non-commercial interest. Speculation in the futures markets has been blamed for fuelling the sharp grain price increases of 2007. Many studies have been conducted to examine the role that futures markets play in the price volatility of the physical commodity (cash price). Some studies have concluded that the futures market was a contributing factor in destabilizing the markets in the short term (FAO, 2010), while others blame the futures markets and speculators entirely for the high volatility in commodity markets (Medlock & Myers, 2009).

Rice futures market has not been included in any of these studies. The thinness of trade in both physical and futures market has prevented much attention to be drawn to the rice futures market. This market was permanently established on the CBOT in October of 1994. The rice futures contracts have much lower trading volume relative to futures contracts of other major grains and agricultural products. However, in the past decade speculative activity has clearly been on the rise in the rice futures market. Open interest and trading volume attributed to speculators (non-commercial interest) have been consistently increasing over the past several years. Therefore, it is time for the rice futures market to be scrutinized and its relationship with the rice cash market studied.

The purpose of this study is to examine the impact of futures trading and changes in speculative positions in the futures market on the cash price volatility of rice in United States. This work builds on Friedman's (1953) argument that speculation by rational (informed)

[1] In this work commercial traders are defined as those who hold positions in both the underlying commodity and in the futures contract of that commodity. The source of this definition is the U.S. Commodity Futures Trading Commission (www.cftc.gov/oce/web/index.htm)

speculators leads to lower cash price volatility, whereas excessively speculative trading by irrational (misinformed) speculators would lead to the destabilization of the cash price.

The theoretical model presented in this study shows that agents form price expectations and decide on storage levels by using the information they receive about the future demand levels. The model demonstrates how use of more accurate information leads to more efficient storage decisions and lower price volatility. Further, it illustrates how basing storage decisions on inaccurate information leads to less efficient storage of goods and higher price volatility.

In order to test the prediction of the theoretical model, two types of empirical analysis are proposed. First Generalized Autoregressive Conditional Heteroskedasticity (GARCH) is used to measure cash price volatility before and after the introduction of the rice futures market. The second method makes use of Vector Autoregressives (VAR) and the Granger Causality Test to measure the impact of change in speculative positions in the futures market on the cash price volatility of rice.

1.2 Objective

The general objective of this work is to present and empirically test a refined form of Friedman's (1953) theory on the impact of speculators on price volatility. This study uses rice futures market as a proxy for the presence of speculators in the rice market.

1.2.1 Specific Objectives

There are several specific objectives that need to be met in order to achieve the goal of this work specified above. The following line indicate these specific objectives.

a) Develop an understanding of the world and US physical rice market.

b) Explain the mechanics of the futures markets and how they are used for speculation in the physical market.

c) Establish a theoretical model to assess the impact of informed and irrational speculation on price volatility.

d) Measure rice cash price volatility prior to and after the introduction of the rice futures market in United State.

    i. Measure international rice price volatility before and after the introduction of the rice futures market in China and on the CBOT.

e) Measure the impact of a sudden rise in futures trading activity as a proxy for the presence of irrational (misinformed) speculators on rice cash price volatility.

In addition to these objectives, the other goal of this work is to draw attention to the rice futures market and establish the ground for further research on the role that a viable rice future market can potentially play in stabilizing the world rice market

1.3 Study Plan

This chapter offers an introduction of the work along with the objectives that this project seeks to meet. Chapter 2 offers a background and a review of the global and U.S. rice markets. It provides a comprehensive literature review on the impact of speculation on price volatility through futures markets. Chapter 3 presents the theoretical model of this thesis. Chapter 4 describes the empirical methods and econometric tools used to test the theory. Chapter 5 discusses the data series used in this work and offers discussion and analysis of the results. Chapter 6 concludes this study by outlining the results and major findings of this work. It discusses possible directions for future studies.

Chapter 2: Background

This chapter is divided into two major sections. The first offers a review of the rice market. The second section presents a comprehensive review of the futures markets as well as the theoretical and empirical work that have been carried out to measure the impact of speculation on price volatility.

2.1 The Rice Market

It is important to understand the international and the U.S. rice markets before we engage in the analysis of the rice futures market in United States. A review of the world rice market dynamics helps one understand the high volatility that seems so embedded in the world price of rice. This global volatility in international prices could also be a major source of volatility in the cash market for rice in the U.S. given that for the most part United States is a price taker. United States produces only about 2% of the world's rice (FAO 2007)[2], and volatility of prices in United States could be greatly affected by the events on the world stage. Therefore, it is important to explore the dynamics of the world rice market before discussing the rice futures market on the CBOT.

2.1.1 World Rice Market

Rice is an important staple food for about half of the world's population. It accounts for 30% of the total cereal production, and ranks second largest produced grain after maize (FAO 2007). However, unlike other important staple foods such as wheat and corn it does not trade in a free market environment. It has a weak connection to other commodities in that it is only produced for human consumption and not for animal feed or bio-fuel (Timmer, 2008).

The market for rice is extremely thin as only about 5% of the rice produced in the world is traded. Therefore, rice has a high consumption to production ratio that has remained fairly

[2] Figure 6 reports the total rice production in United States from 1961-2009

stable over the past few decades. This ratio is higher in South and South East Asian countries than other parts of the world where rice is produced. Approximately 80% of the traded rice is supplied by five countries, Thailand, Vietnam, United States, India, and Pakistan. For the most part rice is produced for domestic consumption. For instance China produces about 30% of world's rice, yet her participation in the world market is close to zero (Timmer, 2009). Countries like Vietnam and India could be exceptions to this general rule, but even they stop exports of rice to secure supplies for domestic consumption[3]. Indeed the government of India's policy of banning rice exports in 2007 is a testimony to how easily the world rice market could be left without any participants in it.

Constant government intervention to control the supply and demand of rice does not allow world prices to play an important role in the decision making of market participants[4]. Siamwalla's et al (1983) analysis of 55 countries showed that only 17 showed some degree of responsiveness to world prices. Therefore, world rice prices do not reflect the true supply and demand levels in the rice market. Government intervention in the market tends to be a sudden reaction to the current situation in the market, which could lead to higher price volatility. Indeed, in the six months between October 2007 and April 2008 the price of rice tripled to about $1000/tonne and reached unseen levels in nominal terms (Dawe & Slayton, 2009)[5]. This unpredictability in the price of rice discourages private participation in the rice market.

The world rice market is one in which its participants for the most part are there to secure domestic supplies to avoid shortages and political instability, or to achieve self-sufficiency for largely domestic political reasons. They are not there to profit from price swings. This has been

[3] Since the early 1980s Thailand has become a consistent exporter of rice with fluctuating quantities. It is now the biggest exporter of rice in the world.
[4] It should be noted that the governments of South and South East Asian countries are the largest participants in the world rice market. Therefore, unless specified any reference to government policy or intervention in the rice market involves those governments.
[5] The world price is the price of Thai 100% B second grade-Figure 7

the norm for decades in the rice market and has led to shortages and price volatility unseen in other major grains' markets.

High level of government involvement in the rice market may lead one to conclude that the rice market is the most regulated and stable of all grain markets. Despite the presence of governments and this degree of regulation, the rice market has experienced and continues to experience tremendous price fluctuations. The sharp price increase of 2007-08 mentioned earlier was followed by a fall of 40% from May to December 2008. A few decades earlier, rice prices increased by $200 per metric tonne per month in 1972 and 1973 after more than a decade of almost no change (Petzel & Monke, 1979). These price fluctuations did not reflect the true scale of shortages or abundance in the world rice market.

It is now generally agreed that perception (rather than reality) about the immediate supply of rice and subsequent policies of some of the Asian governments played a significant role in rapid price increases of 2007 and 2008 (Timmer, 2009). To cite a few examples; the government of India (the second largest exporter in 2007 with 5 mmt[6]) imposed a ban on non-basmati rice in 2007 in order to secure domestic supply to prevent domestic prices from increasing. The government of Thailand, the largest exporter of rice with nearly 10 mmt in 2007 discussed the reduction of exports for the same purpose in March 2007.

On the demand side, the Philippines (the largest importers of rice in the world)[7] announced its plans to increase its rice stocks by two or three folds (Dawe & Slayton, 2009). According to Timmer's (2009) supply and demand model, a 25% increase in short-run demand will lead to a 167% increase in rice prices. Panic led to both shortages and political instability in some countries that depend on rice as a major source for food, the very thing that the government policies intended to avoid.

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[6] mmt = million metric tonnes

[7] The Philippines is expected to import more than 2.4 mmt in 2010 (Source: Food and Agricultural Organization)

Indeed studies show that the structure of the rice market results in such an outcome. Speculation is present in the rice market however, it is in the form of supply speculation and not price speculation. Another characteristic of the rice market is that rice is produced by smallholders and traded by a small group of traders. Unlike other grains rice is not always stored by commercial interest in the market. This characteristic makes collecting inventory data on rice difficult.

According to Timmer (2009) short run price behaviour in commodities that have reliable and readily available inventory data depends on supply behaviour. However, short run price behaviour of commodities with scarce and unreliable inventory data, depends on changing price expectations reflected by hoarding and dishoarding the commodity. The scarcity of data on rice inventories, thinness of the rice trade, and absence of private agents in the market are all structural characteristics of the world rice market, which are the main contributors to the rampant volatility in the rice market.

The world production of rough rice is approximately equal to the production of maize and wheat. However, its trade quantity is much lower than the two. In 2007 the production of rice paddy (rough rice), wheat, and maize stood at 657, 611, and 788 million tonnes respectively. In the same year only 31 million tonnes of rice was traded compared to 110 and 133 million tonnes of maize and wheat respectively (FAO, 2010). Figure 3 provides a juxtaposition of total annual production for rice, wheat and maize over past five decades.

Siamwalla et al (1983) suggest that the creation of the role of seller of last resort or a central market for rice alters these characteristics and reduces rice price volatility. They cite the wheat market as an example where the presence of the United States as a central market (where wheat futures contracts are traded) and a seller of last resort has been a stabilizing factor. It has also been suggested that United States can do the same for the rice market.

2.1.2 United States' Rice Market

United States has traditionally played an important role in the world rice market. With the exception of the Civil War years It has always been a major exporter of rice since the 1700s (Cole, 1927). In the early 1800s U.S. was exporting more than 90% of its rice output which amounted to about 10% of the total trade (Coclanis, 1993). In present day nearly all the rice in the United States is grown in five states: California, Louisiana, Arkansas, Mississippi, and Texas. California produces the short grain high quality japonica type, and the other four produce the indica type given their hotter climates (USDA, 2007).

United States is the only major rice exporting country that is not preoccupied with securing domestic supply. There are also a few other features that make the U.S. unique in world rice market. Only 2% of the annual world rice production belongs to the U.S, yet its share of trade in the global market is more than 10% (Childs & Balwin, 2009)[8]. United States has never put any restrictions on rice trade particularly on the quantity of exports, and it is one of the few major rice producing/exporting countries that respond to world price of rice[9]. However, pricing of rice in United States is done through cooperative pool pricing, and not competitive auctions (McKenzie, Jiang, Djunaidi, Hoffman, & Wailes, 2002). Government intervention in export of rice from the US is limited to export subsidies and quantity produced (Siamwalla & Haykin, 1983).

The U.S. government has never implemented a policy to build rice stockpiles similar to other major rice producing countries. There have been policies that have indirectly affected exports of rice from the U.S. In response to rice price volatility and in order to lower it, the US government implemented the Rice Marketing Loan in 1985. This resulted in the U.S. rice prices

[8] The US' share of global rice trade was much higher. From the early 1700s until the beginning of the civil war the United States was the largest exporter of rice in the world. It even exported to major rice producing countries such as China. Due to the civil war United States lost this status only to regain it in the beginning of the 1960s and maintaining it until the middle of 1980s (Coclanis, 1993).

[9] Prices in Thailand's domestic market also respond to world prices

being above the world price for almost two decades and effectively reduced U.S. rice exports while increasing government rice stocks (Taylor, Bessler, Waller, & Rister, 1996).

Despite the relatively liberal policies toward rice exports, United States is still not a seller of last resort in the world rice market. Perhaps the only issue that has prevented the United States from acting as the seller of last resort in the rice market is that unlike wheat, U.S. is not a large enough producer of rice. Therefore, it can never build enough stocks to meet a sudden surge in demand from the major rice consuming countries (Siamwalla & Haykin, 1983).

The world rice market needs "relevant stockholdings" which implies that stored rice can affect world prices. Many countries store rice, but this does not mean that they have the intention of releasing the rice in stock into the world market. Therefore, the existence of an offshore storage where storage of rice is done by speculators or private enterprise could be an important factor in stabilizing the market. This offshore storage should not be subjected to government policies of various countries. The speculators should be motivated to get involved in this market for profit.

Only in the U.S. does such a central market exist for rice in the form of a futures market. The results of this study could shed some light on whether rice futures markets are a viable solution to reducing (even if not eliminating) the seemingly inherent volatility in the rice market.

2.2 Futures Markets and the Impact of Speculation on Price Volatility

Prior to describing the nature of the rice futures market in United States, it is important to have a broad understanding of the mechanics of futures markets in general and their impact on cash price volatility in particular by speculative behaviour.

2.2.1 Futures Markets and Contracts

Futures contracts are standardized contracts that oblige their holders to deliver or take delivery of a specified quantity of a specified commodity at a specified date in the future. These contracts are traded on futures exchanges around the world. The most notable exchange is the Chicago Board of Trade (CBOT), which was founded in 1848 and listed the first futures contract in 1864. The agent who enters a futures contract to take delivery of a commodity in the future is said to be taking a “long” position. The one who is obliged to deliver the commodity at a specified date in the future is said to be taking a “short” position.

The speculative agent with the “long” position expects prices to rise and the one with the short position expects prices to decline by the time the futures contract s/he has entered in matures. For example an agent who takes a “long” position in February 2012 rice futures contract believes that rice prices in February 2012 will be higher than what the market currently expects rice prices to be in February 2012. The agent with a “short” position anticipates the opposite.

There is a “short” position for every “long” position. Therefore, all gains in a “long” or “short” position are offset by losses in the opposing “short” or “long” positions respectively. The role of the futures market in the economy extends beyond providing a platform for individuals to engage in a zero sum game. The presence of the futures contracts and markets allows for a more complete market.

A complete market is one in which there exist enough investment instruments to allow investors to bet on or protect themselves against (either directly or indirectly by combining different existing instruments) all possible outcomes in the market. Transaction costs prevent the existence of a market that takes into account all states of the world. Yet uncertainty about the future state of the world concerns investors and they look for ways to be as prepared for any future state of the world as possible. They do this either by hedging their current position or speculating that a particular state of the world will materialize (Strong & Walker, 1987).

Futures market allows market participants (hedgers and speculators) to do that. Futures market and futures contracts provide a cost effective way for agents to prepare for anticipated or unanticipated states of the world that affect market outcomes.

2.2.2 Speculation and Price Volatility

Participants in the futures market can be divided into two groups: hedgers and speculators. Hedgers enter the futures market to lock the price of a commodity they plan to buy or sell in the future. Speculators enter the futures market to bet on the price movement of a particular commodity, and hence are in the futures market for profits.

As hedgers go "long" or "short" in the futures market depending on whether they wish to buy or sell (respectively) a commodity in the future, speculators take the opposite side of the contract and bear the price risk that initially rested with the hedgers. In order to transfer the risk to speculators, hedgers are willing to pay a premium. The expectation of receiving this premium is one of the reasons that speculators enter the futures market and bear the price risk (Keynes, 1930)[10].

Therefore, speculators are a necessary part of the futures market, if it is to function as a place where traders of the physical commodity can hedge their positions. Despite the role they play in mitigating the risk to the physical market participants, futures contracts are viewed with concern as many believe they may also have negative impacts on the price and allocation of the underlying commodity.

Futures contracts and markets have been a subject of controversy from their inception in Chicago in 1864, over their impact on the spot (cash) price of the physical commodity. Politicians and many traders in the physical (cash) market believe that speculation in the futures

[10] Keynes asserts that the "short" position of hedgers requires the speculators to take a "long" position. The speculators take that position if the expected future price of the commodity in the futures contract is higher than the current future price specified in the contract (i.e. $E(S_{t+1}) > F_t$), where $E(S_{t+1})$ is the expected spot price in the future and F_t is the current future price reflected in the futures contract (Keynes, 1930).

market leads to volatility (destabilization) of the spot market (Antoniou & Holmes, 1995). The impact of speculation on the stability of the cash market has been a subject of numerous studies.

Friedman (1953) asserts that there is no reason for speculation to lead to the destabilization of prices in the physical market, because speculators buy when prices are low (low demand and high supply) and sell when prices are high (high demand and low supply). This course of action by speculators causes prices to rise when they are low and decline when they are high (Friedman, 1953). In addition, Friedman argues that saying speculation is destabilizing is equivalent to saying that speculators lose money[11]. According to Friedman only irrational (misinformed) speculators destabilize prices.

Hart et al. (1986)[12] take an opposite view and argue that in a market where rational agents have access to identical information and history, speculation may increase price volatility. According to them, rational speculators base their decision to enter the market in this period on the probability of high demand level in the next period. In the Hart et al. model speculators buy and store a commodity if they receive the high demand signal for next period. It should be noted that the signal only indicates high probability and therefore the next period high demand may not materialize. False signal means that next period speculators will dump the commodity in the physical market leading to a further decrease in prices[13]. Therefore, when demand is low, the lowest price in the absence of speculators is higher than the lowest price in their presence. The presence of speculators widens the range over which prices fluctuate (Hart & Krept, 1986).

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[11] According to Friedman speculators would destabilize the market if they buy when prices are high, leading to further rise in prices, and if they sell when prices low, leading to further decline in prices. This action will lead to losses for speculators.

[12] Although Hart and Kreps (1986) paper does not assess the impact of futures market on the spot market, it offers a comprehensive study of the impact of speculation on the spot price of the physical commodity. Therefore citing their work is warranted given that speculation is an essential component of the futures market.

[13] The model assumes speculators can only store for one period, demand for the commodity is elastic, and every period a fresh fixed amount of the commodity is supplied to the market irrespective of consumers' and speculators' demands and actions.

This may not be true if speculators have foresight. In the extreme case of perfect foresight where next period's prices are visible in this period, the presence of speculators does not lead to wider range of prices. There are two cases in perfect foresight: 1) $P_{t+1} > P_t$ or 2) $P_{t+1} < P_t$.

In the first case, there will be speculative demand in the market in period t given that speculators know that prices in the next period (t+1) will be higher. This extra demand by speculators means a higher price in period t than the lowest price without speculators in that period. In period t+1, when speculators sell their stored commodity, prices would be lower than what they would be without speculators.

In the second case, speculators do not enter the market to buy the commodity at time t knowing that prices will be lower at t+1. In this case prices are not raised further in t relative to t+1 because there will not be an additional demand from speculators. Also, prices are not depressed further in t+1 because there are no additional supplies released into the market by speculators. In general Hart et al. assert that complete foresight is required for speculation to be stabilizing (Hart & Krept, 1986). Figure 1 demonstrates this. In both cases in figure 1 the width of price range (volatility) between the two periods is lower when speculators have foresight and are informed than when they are not.

Further in their analysis, Hart et al. indicate that speculation could lead to stability from the production side. Current increase in speculative demand could also be a signal to producers that demand for their products will be higher in the future. As a result producers invest in increasing capacity in the current period in order to produce more in later periods. Under these circumstances prices would be lower in the future when demand is high than they would have been without the extra production.

2.2.3 Speculation through Futures Markets and Cash Price Volatility

Speculation through a futures market, where speculators do not necessarily store the physical commodity, may have additional and somewhat distinct ways of affecting the volatility of prices in the physical market. Miller (1991) points out that the interdependency of the physical (cash) and the futures market requires that price changes in one be transferred to the other. This could lead to volatility, which is exacerbated if markets are separated in terms of trading hours, speed with which trading can be done, and transactions costs etc (Miller, 1991).

Valentine (1995) mentions that value of the futures contracts exceed the value of the physical underlying asset because there can be an unlimited number of futures contracts. This makes unlimited speculation possible, which can lead to higher or lower prices than otherwise would be possible in the physical market. However, this flexibility in the futures market can absorb the shocks in physical market. A supply shortage leads to higher prices in the physical market. However the futures market can mitigate the price increase in the physical market by allowing traders to take long positions and claim future supplies rather than seeking the goods now for later use (Valentine, 1995).

Powers (1970) addresses the role that futures markets play in increasing information about the fundamentals (supply and demand) in the physical market. According to Powers a price series has a systematic and a random component (2.1). Therefore, variance and volatility in a price series also have a random and systematic component (2.2).

$$P_t = S_t + R_t \tag{2.1}$$

P_t = price time-series S_t = systematic component R_t = Random component

$$V(P_t) = V(S_t) + V(R_t) \quad V = \text{variance} \tag{2.2}$$

The systematic part of the price series reflects the changes in the fundamentals of the commodity such as supply and demand. The random part reflects the "noise" and movement in price that is not related to the fundamentals. This component distorts the message that prices (which are essential for further allocation of resources in the economy), send. The random component (disturbance) may arise from insufficient information and distorted price messages sent to the market. This disturbance may have several sources.

Kawai (1983) points to the importance of the source of random disturbances in determining whether the introduction of futures market has any impact on cash price volatility. In Kawai's model there are three types of agents in the physical market: consumers, producers, and inventory carriers (dealers). The introduction of the futures market could have a stabilizing or destabilizing effect depending on which of these agents is the source of volatility. For example, when dealers are infinitely risk averse, the introduction of a futures market increases price stability in the cash market if random disturbances are predominantly coming from the activities of consumers. However, the opposite would be true, if the disturbances were predominantly from the production or dealer side (Kawai, 1983)[14].

The more informed economic agents are about the fundamentals the more they will base their decisions on real changes in supply and demand. The futures market allows for a better and faster flow of information, hence reducing the variance in the random component of the price series. Prices in the futures contracts include information on production, storage, supplies, demand, current cash price etc. This information, available through numerous institutions and exchanges around the world is used by speculator and cash market participants alike (Powers, 1970)[15].

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[14] Kawai's model is applied to storable commodities

[15] Although Powers' analysis shows that the random component of price variance is reduced after the introduction of the futures market, it does not address the impact of the futures market on the variance of the systematic component of the price series. He acknowledges that the introduction of the futures market may have a different

Higher quantity of information does not necessarily imply higher quality of information. Cox (1976) addresses this issue by analyzing the influence that speculators could have on the allocation of storable goods in the cash market. Futures markets attract traders (speculators) who are only interested in the price movement of the underlying commodity, do not handle it, and would not be present in the market had it not been for the futures market. The speculators take net long or short positions, which implies that hedgers could be taking the opposite position. Therefore, speculators' belief about the future price leads to the reallocation of some of the current physical stock hence changing the cash price[16].

By this analogy misinformed speculators can alter price expectations in the spot market that do not really reflect true market fundamentals[17]. Whether speculators who spend time and resources to acquire information about the underlying commodity have high quality information to bring efficiency to the market is still debated (Cox, 1976).

However, Ross' (1989) argument of the relationship between information flow volatility and price volatility renders the information quality argument somewhat immaterial. Ross' model asserts that in the absence of arbitrage[18], the volatility of prices should equal the volatility of information flow (Ross, 1989). This could imply that the introduction of futures markets, while increasing the volume of available information, also increases the volatility of information flow and lead to higher price volatility.

It may not be possible to assert with certainty whether futures markets lead to volatility in cash prices or not. None of the literature reviewed in this section reach a general conclusion

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effect on the variance of the systematic component of seasonally produced and storable commodities (Powers, 1970).

[16] Hedgers here are not just producers of the commodity but also agents who may use the underlying commodity in the production of other goods.

[17] This argument could perhaps be applied to when two speculators enter a futures contract (no hedgers involved). Participants in the physical market view this transaction from outside. Based on their belief about which speculator is better at predicting the future price, they can shift and reallocate the physical stock.

[18] Ross' assumption has two major assumptions: 1) markets are efficient (no arbitrage) 2) information for period t only becomes available in period t).

about the impact of the futures market on cash price volatility. However, collectively they lay the theoretical ground for a better understanding of the rice futures market in the U.S. and its impact on rice cash price volatility.

2.2.4 Futures Market and Cash Price Volatility: Empirical Evidence

In addition to theoretical works, there have been many empirical studies on the impact of futures trading on cash price volatility. Many agricultural and non-agricultural commodities have been the subject of these studies. These studies measure cash price volatility before and after the introduction of the futures market. The following paragraphs offer a review of several of these works.

The U.S. congress banned the trading of onion futures contracts through the Onion Futures Act in August 1958 (U.S. Code, 1958). The implementation of this act ignited research on effect of futures trading on cash price volatility. Early works by researchers such as Gray 1959 concluded that onion futures contract trading reduced the seasonal spot price range in the onion market (Gray, 1959). Gray's 1963 work suggested that after the banning of the futures trading in the onion market, the price range was increasing and going back to its pre futures trading years (Gray, 1963). Building on this, subsequent research was conducted to evaluate the impact of futures trading in other commodities' markets.

These early works concluded that the futures market: a) lowers seasonal price range due to the presence of speculative support at harvest time. Speculators are willing to take ownership of the harvest, hence prices do not drop, and this leads to more grain being stored by the farmer. More grain in store prevents prices from rising too high later in the year b) acts as a guide for better production planning and hence leads to less annual price fluctuations c) allows for better anticipation of price adjustments and rational storage decisions by commercial traders, which would lead to lower volatility (Powers, 1970), (Leuthold & Taylor, 1974), and (Morgan, 1999).

The futures market achieves the three points above by facilitating information flow through the actions of thousands of traders in the market. More information causes the market price to be closer to the equilibrium price which would signal the true level of supply and demand. Therefore, there will be less variability in cash price once the decision of suppliers and consumers are based on close to equilibrium prices (Powers, 1970).

There have only been a few studies on rough rice futures market in United States. These works have focused on market efficiency and estimating whether the rice futures market is biased[19]. In a 2002 paper, McKenzie et al used various methods (Johansen cointegration procedure and Error Correction Model) to analyse the ability of the current futures price to provide an unbiased estimate of cash price when the contract matures. They find that rice futures prices outperformed both of those methods in forecasting the future cash price of rice in short and long run (McKenzie, Jiang, Djunaidi, Hoffman, & Wailes, 2002).

Taylor et al. (1996) study the relationship between US rough rice cash prices, Thai milled rice price and rough rice futures price (Taylor, Bessler, Waller, & Rister, 1996). A detailed review of this work will be offered in section 2.2.7.

2.2.5 Cash Price Volatility before and after the Introduction of Futures Market

Futures markets have allowed non-commercial interest and speculative money to enter the commodities market. This has given rise to the question of whether the presence of this speculative money and generally futures trading has increased cash price volatility. It is said that a well functioning futures market guides the commodity storage decision and smoothes its release into the market (Morgan, 1999). Majority of the analyses using various methodologies show that futures trading has indeed reduced cash price volatility.

[19] Downward biased futures price means lower current futures price than what is expected to be received at maturity. Upward biased futures price means higher current futures price than what is expected to be received at maturity.

Powers (1970) used the Variate Difference Method to separate the random (noise) component of the time-series price from the systematic component[20] for pork bellies and cattle before and after introduction of futures trading for these two commodities. He found that the variance of the random component was reduced after the introduction of the futures trading for both commodities (Powers, 1970).

Leuthold et al (1974) simply used the variance of the monthly average cash price of cattle around two eight year period averages. They concluded that this variance was significantly lower in the second eight year period (during futures trading) than in the first eight year period (before futures trading).

Morgan (1999) used standard deviation to measure cash price volatility of potato in Britain and concluded that after the introduction of futures trading in 1980, cash price volatility has been reduced.

Antoniou et al (1992) used the GARCH model to represent the cash price return volatility of crude oil and their results strongly rejected the null of no change in volatility pre and post futures trading (Antoniou & Foster, 1992). In addition, the coefficient of their cash return volatility was less important in explaining cash returns after the introduction of futures trading. They tested both models for unit root to assess the persistence of the shocks in the crude market and found that the post future volatility model was stationary whereas that of pre-futures was not.

Their results also indicated that post introduction of futures trading, 'news' becomes more relevant in explaining the conditional variance of cash return as information flow and hence reaction to news is faster because of the futures market. In contrast, lagged volatility becomes less important in explaining current period variance, and the authors attribute this to the fact that any risk posed by lagged volatility could be hedged away[21].

[20] Systematic component refers to fundamental economic conditions such supply and demand

[21] The detailed model used by the authors will be discussed in the Model section of this thesis.

In this study the GARCH model will be used to measure the cash price volatility of rice before and after the introduction of rough rice futures trading on CBOT. The rice futures market is a thinly traded market. Therefore, trading frequency may play a part in determining whether a futures market is beneficial in allowing for better flow of information in the market for the underlying commodity.

Using the GARCH volatility model Holmes (1996) demonstrate that a thinly traded futures market lowered the volatility in the cash price of the underlying asset[22]. By analysing the components of the GARCH volatility model, he shows that despite a low trading volume in the futures market, the information flow was improved and persistence of shocks (new information) in the market was reduced[23]. This implies that despite low frequency of trade, the futures market could still facilitate information flow and price discovery.

2.2.6 Level of Futures Trading Activity and Cash Price Volatility

More recent literature has focused on the question of how trading activity in an existing futures market affects spot price volatility. This section is concerned with the impact of change in futures trading volume and open interest (i.e. level of futures trading activity) on cash price volatility. The activity level of the futures market contributes to the volatility in the cash market in three ways: First is when manipulation and technical factors distort futures prices, and traders in the futures market act on false signals. Second, lack of speculation in the futures market and pure hedge trading in that market could lead to instability in the cash market. The hedging pressure in the futures market affects the cash market through dealers and market makers who are now bearing the risk from both the cash and the futures market.

Finally, if traders in the futures market are not as well informed as the participants in the cash market, then the actions of the former lead to distortions in the cash price. The better

[22] The futures contracts were written for FTSE Eurotrack 100 index which covers the largest capitalized companies in 12 European countries.
[23] Please see "Model" section of this work for a detailed analysis of the GARCH volatility model.

informed commercial traders in the cash market will then use this distortion to generate profit (through arbitrage) and inadvertently stabilize the futures market at the expense of increasing volatility in the cash market (Figlewski, 1981). The last point implies that due to less friction and lower transaction costs, prices adjust much faster in the futures market. This price adjustment enters the underlying cash market through arbitrage and given that normally large transactions are required to generate profits from arbitrage, the cash market becomes more volatile (Antoniou & Foster, 1992).

Harris (1989) found short run volatility in the stock price returns as trading volume in S&P 500 index futures contract increased. Large transactions in the futures market are normally accompanied by related transactions in the cash market. Therefore, lack of liquidity in the cash market (in terms of the volume of transaction) and higher trading volume (activity) in the futures market would lead to higher volatility in the cash market. He found no such relationship in the long run once liquidity has entered the market (Harris, 1989).

Another interesting study done by Adrangi and Chatrath (1998) on exchange rates found no relationship between the open interest position of large hedgers and change in cash price volatility. However, they found such relationship between open interest and cash price volatility once there was an increase in open interest position of speculators in the market (Adrangi & Chatrath, 1998).

Epps et al (1976) suggest that if traders disagree on the magnitude of the impact of new information on asset valuation, then both trading volume and price volatility would rise (Epps & Epps, 1976). Their study was not specifically directed at the interaction between futures trading volume and cash price volatility, but their result is applicable to that field. The rapid absorption of the information in the futures market and traders' decision based on their interpretation of the new information could increase futures trading volume and in turn affect the cash price volatility as described earlier.

Bessembinder et al (1992) found that cash price volatility decreased after the introduction of equity futures market. However, they conclude that an increase in unexpected trading volume in equity futures market increased cash price volatility (BESSEMBINDER & SEGUIN, 1992). In addition, they found a reduction in cash price volatility as open interests position increased in the futures market.

There have been only a few empirical studies on the effect of the level of futures trading on cash price volatility for agricultural commodities. Yang et al (2005) study the lead-lag relationship between the futures trading level and cash price volatility for several agricultural commodities (not including rice). They used the Granger Causality test and the Generalized Forecast Error Variance Decomposition (GFEVD) to examine the effect of an increase in future trading volume and open interest positions on cash price volatility (which they modeled using GARCH 1,1). They concluded that an unexpected increase in futures trading volume of these commodities caused an increase in cash price volatility for most of the commodities under examination (Yang, Balyeat, & Leatham, 2005).

2.2.7 World and U.S. Rice Price: Pre and Post Introduction of Rice Futures on CBOT

The relationship between U.S. rice and world rice prices has come under scrutiny in the context of studying how integrated the world rice market is. In evaluating the degree of integration in the world rice market Petzel et al (1979) studied the reaction of rice prices in United States to changes in world prices. They used the Granger causality test and found that Thai prices from the previous month explained the current prices of US rice (Petzel & Monke, 1979). Understanding this relationship has become more interesting with the introduction of the rice futures trading in United States.

Taylor et al (1996) concluded that there is a long run equilibrium price relationship between the rough rice futures market and Thai rice. Therefore, the rough rice futures market in

United States could be an important price discovery tool in the international rice market or at least it can be relied upon to convey new information in the international rice market (Taylor, Bessler, Waller, & Rister, 1996). This price discovery role by a central market has been sought by experts in international rice market for decades and was discussed in earlier sections.

Similar studies in other areas may shed light on how a thinly traded futures market can link the larger world market to the domestic cash market. Martikainen et al (1994) show that the information from world's stock markets is transmitted to the Finnish stock market through the Finnish stock index futures. They found that world stock market returns Granger cause changes in the Finnish index futures returns. Subsequently the Finnish index futures returns Granger cause the change in the returns of the Finnish stock market (Martikainen & Puttonen, 1994). Therefore, the presence of a futures market, however thin could be a communicator of information in a particular market.

2.2.8 United States' Rice Futures Market

The first rice futures market was established in the Tokugawa period in the city of Osaka in Japan in 1730. Research shows that this futures market possessed all the characteristics of a modern futures market (Schaede, 1989)[24]. The New Orleans rice futures market which was established in the mid 1970's and closed a few years later, was perhaps the first attempt at allowing in investors and speculators into the rice market in United States[25].

Rough Rice futures contracts began trading for a second time in U.S. on the Chicago Board of Trade in 1994[26]. Each futures contract obliges the owner to purchase or sell

[24] Same source claims that this market is the oldest modern futures market in the world.

[25] The U.S. government policy of floor loan rate led to a domestic price higher than the world price, and little to no variation in the market price. Therefore, a central market with the desirable objective mentioned above could not exist.

[26] Starting in 1986 rice futures resumed trading on the Chicago Rice & Cotton Exchange, which then merged with Mid American Exchange. Rice futures traded there until their move to CBOT in October 1994. The contract is for the delivery of No. 2 U.S. long grain or a better quality. Contracts size is for 2000 hundredweight of rough rice (200,000 pounds) (CBOT, Rough Rice Futures, 2008).

approximately 91 tons (or 2000 hundredweights) of long grain no. 2 rough rice with a milling yield of not less than 65% (CME, 2011)[27].

With the introduction of the futures market on the CBOT, the entrance of speculators and non-commercial interest into the rice market in the United States was facilitated, and there has been a steady growth of non-commercial interest in the market. For example, in 1994 non-commercial long positions (Figure 8) in the market as a percentage of total reported long positions was about 23% compared to 55% at end of 2009 (CFTC, 2009)[28]. However, the rice futures market is still considered a very thin market relative to the other grain futures market in United States namely maize and wheat. For instance, during the last trading week of 2009, the wheat futures market had 18 times and 117 times more non-commercial long and short open interest positions respectively than the rough rice futures market (CFTC, 2009). The trading volume of maize and wheat futures contracts expiring in May 2010 were 1183 and 2783 respectively, whereas that of rough rice was only 321 (CBOT, 2010)[29].

Despite the thinness of trade in the rice futures market, it would be interesting to evaluate its impact on the rice inventories and cash prices in United States and abroad. The CBOT may not be large enough to accommodate the speculative and hedging position of all rice market participants in the world but it can act as a launching pad for the creation and expansion of other such markets elsewhere in the world.

Indeed in March 2009 Zhengzhou Commodity Exchange introduced rice futures, which could be the first step in establishing a large central market for rice where private speculation can take place (Forbes, 2011). It is therefore, essential to evaluate the 16 year performance of the rice

[27] Figure 8 shows the complete specification of a rough rice futures contract

[28] The share of non-commercial short position in total reported short positions has been consistently falling since 1994. At the end of 2009 it stood at 8%. This could be due to the usage of short contracts as hedging vehicles by farmers or the board, and the fact that the price of rice has not shown sign of decline since that time to motivate speculator to take short positions in the futures market.

[29] March 18th 2010

futures market on the CBOT in terms of affecting the volatility of the cash (spot) price of rice and its impact on world rice prices.

The impact of futures contract trading on cash prices of the underlying commodity has been a topic of discussion in agricultural economics for many years. Many studies have been done on various commodities' futures trading. Futures contracts are used by hedgers to lock their profit/revenue from the crops they cultivate. They are also used by speculators to bet on the price direction of commodities. Futures contracts are the only vehicles that speculators (non-commercial traders) can use to profit from the price movement of a commodity, without having to take possession of the actual commodity[30]. It is the actions of the latter in the futures market that has given rise to numerous works on the impact of futures contract trading on the cash price of the underlying commodity.

This study has been motivated by allegations that the activity of non-commercial interest in the futures market is responsible for cash price volatility. The rice futures market with all the unique characteristics that the rice market has will enable us to test theories relating speculation to price volatility. Almost all commodities with traded futures contracts on the CBOT have been analyzed, and the analysis has been focused on assessing the cash price volatility prior to and after the establishment of the futures market. More recent work has been focused on analysing the impact of the level of trading activity in the futures market on cash price volatility. In this work both analyses will be conducted to examine the theory that will be put forward in the next chapter.

2.3 Summary

The world rice market has experienced significant price volatility over the past few years. The mechanics of the rice market do not allow it to function and allocate the rice based on prices.

[30] By owning exchange traded funds, investors trade futures contracts indirectly.

United States is a rice producer and in recent years has become a major supplier of rice to the world market. It hosts the only major rice futures market in the world.

Futures markets have played a key role in allowing market participants to hedge their positions. They have also attracted speculative non-commercial interests to the market. The actions of this group and their impact on cash price volatility have been a subject of many theoretical and empirical studies. These studies have failed to provide a clear answer on the impact of speculation on price volatility. However, they provide the necessary theoretical and empirical framework for studying the impact of futures trading on rice price volatility.

Chapter 3: Theory

This chapter presents the theoretical model of this study, which is built on Milton Friedman's (1953) work on the impact of speculation on price volatility. It begins by presenting the general theory and describing how it applies to this thesis. The second part of this chapter discusses the details of the theoretical model that this thesis tests.

3.1 The General Theory and its Application to this Study

The general theory of this thesis is that speculation lowers price variation from one period to the next, unless it is carried out by irrational speculators. The following paragraphs explain how this theory could be applied to examine the impact of speculation in the rice futures market on its cash price volatility.

In Friedman's (1953) work, speculators buy and store the commodity, which makes them different from the speculators in the futures market. The latter do not take possession of the underlying commodity and simply close their positions by entering the opposite side of the futures contract. It may seem that speculators' actions in the futures market do not have any impact on the physical market.

On closer inspection however, the speculators' actions and foresight in the futures market may entice the actors in the physical market to reallocate the commodity for sale or purchase to a later period. Therefore, the speculators in the futures market could have an indirect effect on the allocation of the commodity in the physical market, making Friedman's theoretical work applicable to a situation where speculators act through the futures market.

As described earlier the futures market increases the flow and quantity of information. The price of the underlying commodity indicated in the futures contract reveals market participants' expectations about the future of supply and demand of that commodity. These expectations are formed through research done by many agents with commercial and non-commercial interests. Needless to say, the non-commercial interest (speculators) would not be there without the existence of a futures market.

Friedman (1953) asserts that only irrational speculators who act on misinformation destabilize the market. The proxy for the presence of irrational speculators in the futures market could be a sudden rise in the activity of speculators in the futures market. The unanticipated temporary presence of additional non-commercial interest in the futures market could lead (directly or indirectly) to higher price volatility.

Friedman argues that irrational speculators lose money. They buy when prices are high and sell when prices are low, hence increasing the magnitude of the price variation. The sudden rise in the futures market activity is captured by a rise in volume and open interests in the futures contracts. Therefore, we will be looking at the impact of speculators' trading activities in an established futures market on price volatility in the physical market.

3.2 The Theoretical Model

The following paragraphs explain the details of the theoretical model of this work. The model illustrates how speculation could lead to lower price volatility and how the presence of irrational speculators leads to higher price volatility (the full mathematical derivation of the results is available in appendix A) [31].

The first part of this section describes the parameters and assumptions of the theoretical model. It describes price volatility under the condition of certainty about the future. In the second part uncertainty about the future is added to the model. Under uncertainty, the model compares price volatility in a market with speculators to one without speculators.

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[31] I am forever grateful to my supervisor Professor James Vercammen for developing this section, which I call a refined form of Friedman's theory. The theoretical framework of this study could not have been presented with such clarity had it not been for his input.

Parameters and Assumptions

The theory is based on a two period model (t_1 and t_2). In the first period (t_1), individuals are endowed with a fixed quantity of a good (Q_1). Some of this good is consumed in the first period (t_1) and some is stored (with a cost = m) for consumption in the second period (t_2). Therefore, the quantity stored (S) in the first period dictates the level of prices in period 1 and period 2 (P_1 and P_2 respectively). 3.1 and 3.2 present P_1 and P_2 as a function of S.

$$P_1 = a - (Q_1 - S) \quad (3.1)$$
$$P_2 = \tilde{\alpha} - S \quad (3.2)$$

$\tilde{\alpha}$ is the demand level in the t_2 which could either be high or low

(S*) is the equilibrium quantity of the stored good. It is the amount of storage that minimizes the difference between P_2 and P_1. As (3.3) indicates the minimum difference between P_2 and P_1 should equal the storage cost (m)[32].

$$P_2 - P_1 = m \quad (3.3)$$

If $(P_2 - P_1) > m$, then more can be stored in t_1 to be released in t_2 and lower P_2. Therefore, storage will continue until (3.3) is achieved. $P_2 - P_1 < m$, would signify that too much is stored in t_1 and losses would occur carrying the goods from t_1 to t_2. Therefore, less should be stored to establish the equality in (3.3). It is worth mentioning that the storage cost (m) is expressed in terms of the good (i.e. it costs m goods to store the good in t_1 for consumption in t_2).

The Model with Uncertainty

The assumption so far, has been that demand levels for the endowed good are the same in both periods. However, demand levels (relative to supply levels) are subject to change from one period to another due to a number of factors. Indeed the reason for the existence of a futures market is to protect market participants from potential variation and change in the fundamentals.

[32] This is the law of one price which indicates that the difference in price of a good between two periods must equal the cost of carrying that good from one period to the next. This assumes that all other factors such as demand level remain unchanged between the two periods.

The demand for the good in the second period (t_2) of our model could be high or low (α_H or α_L respectively). This uncertainty in the demand level in the second period may cause more or less than the equilibrium level of stocks be carried over to t_2 from t_1.

Therefore, with the element of uncertainty in second period demand level, the measure of price variability between the two periods, expressed as the expected squared price difference (ESPD) between t_2 and t_1 would become:

$$E(P_2 - P_1)^2 = m^2 + \frac{1}{4}(\alpha_H - \alpha_L) \tag{3.4}$$

ESPD as a measure of volatility is higher when there is uncertainty about demand levels in the second period. Inequality (3.5) demonstrates that volatility is higher when there is uncertainty about next period's demand level:

$$m^2 + \frac{1}{4}(\alpha_H - \alpha_L) > m^2 \tag{3.5}$$

m^2 is the ESPD when demand level is certain in the second period (i.e 3.3 squared).

In reality uncertainty is always present and there is always under or over allocation of goods to another period, which may cause prices to move away from the equilibrium point. The purpose of this study is to assess whether speculation could lower this under or over allocation of goods to another period. Could the presence of speculators in the market at least reduce the ESPD shown in (3.4) and bring its value closer to the m^2? In other words, could speculation lower price volatility?

The Model with Speculators

The two period model presented here makes the following assumptions to incorporate speculators.

1) There are two types of speculators

a. Speculators who act on information about the demand level in the second period. The quality of this information (ϵ), determines how likely it is for particular demand level to occur in the second period.

b. Speculators who are convinced that demand level in the second period will be high, no matter what ϵ indicates. These speculators either do not have access to the information that the first group has, or have some preconceived ideas of where the market is heading. Therefore, they are always bullish no matter what the information indicates. The degree of this bullishness is represented by δ.

2) There is an equal chance that the news regarding the demand level in t_2 indicates either α_H or α_L.

3) The chances that one of α_H or α_L materializes depends on which state ϵ favours and its magnitude.

Therefore, the expression for the expected squared price difference (ESPD) between the first and the second period in the market with speculators is as follows:

$$E_{WS}(P_2 - P_1)^2 = \frac{1}{2}[(\frac{1}{2}+\epsilon)(P_2^L(A) - P_1(A))^2 + (\frac{1}{2}-\epsilon)(P_2^H(A) - P_1(A))^2]$$
$$+\frac{1}{2}[(\frac{1}{2}-\epsilon)(P_2^L(B) - P_1(B))^2 + (\frac{1}{2}+\epsilon)(P_2^H(B) - P_1(B))^2] \quad (3.6)$$

In state A, news in t_1 indicates that demand in the second period will be low (i.e. $\tilde{\alpha} = \alpha_L$). In State B, news in t_1 indicates that demand in the second period (t_2) will be high (i.e. $\tilde{\alpha} = \alpha_H$). The probability of either news states A or B happening is 50%.

There are two possible outcomes once either state A or B is revealed. The actual demand level in the second period could be either low (α_L) or high (α_H). In case of state A, the probability that demand will be low (i.e. $\tilde{\alpha} = \alpha_L$) in the second period is $(\frac{1}{2}+\epsilon)$ and the probability of $\tilde{\alpha} = \alpha_H$is $(\frac{1}{2} - \epsilon)$. In case of state B, the probability of $\tilde{\alpha} = \alpha_L$is $(\frac{1}{2} - \epsilon)$ and of $\tilde{\alpha} = \alpha_H$ is $(\frac{1}{2} + \epsilon)$.

$P_2^L(A)$ indicates P_2 in state A, where actual demand level in the second period is low. $P_2^L(B)$ signifies P_2 in state B, where actual demand level in the second period is low. The other two notations ($P_2^H(A)$ and $P_2^H(B)$) represent period two prices in states A and B, where actual demand level is high in the second period.

Equation (3.6) and the left hand side of inequality (3.5) are the ESPD for the markets with and without speculators respectively. The following sentences describe the dynamics and ESPD value in the market with speculators, and compare the results to the ones from the market without speculators.

NS = without speculators
WS = with speculators

$$E_{NS}(P_2 - P_1)^2 = m^2 + \frac{1}{4}(\alpha_H - \alpha_L) = \text{ESPD}_{\text{NS}} \qquad (3.7)$$

$$E_{WS}(P_2 - P_1)^2 = \delta^2(\alpha_H - \alpha_L)^2 + 2\delta m(\alpha_H - \alpha_L) - \epsilon^2(\alpha_H - \alpha_L)^2 + m^2 + \frac{1}{4}(\alpha_H - \alpha_L)^2 = \text{ESPD}_{\text{WS}} \qquad (3.8)$$

Two immediate results emerge from equation (3.8). The first is that as ϵ increases, ESPD_{WS} falls. As indicated earlier, ϵ signifies the quality of the information available in t_1 about the level of demand in the t_2 (i.e. $\tilde{\alpha}$).

As ϵ increases there will be less uncertainty about the future demand, a more efficient allocation of goods for consumption in the second period takes place. ESPD_{WS}, which captures the price difference between the two periods, falls. Speculation would be absent if $\epsilon = 0$. Therefore, $\epsilon > 0$ implies that speculators enter the market and act on this information regarding demand level in the next period. Therefore (3.8) demonstrates that speculation lowers the price volatility and leads to more stability.

The second result from (3.8) is that as δ increases, $ESPD_{WS}$ (i.e. price volatility) also increases. As explained earlier, δ represents the degree of irrationality (bullishness) of uninformed speculators. This result confirms Friedman's argument that only irrational speculators destabilize the market. In the absence of irrational speculators (δ = 0), and when speculators, who are acting on $\epsilon > 0$ are present, there is less volatility ($ESPD_{WS} < ESPD_{NS}$). However, as δ increases for a given ϵ, the positive effects of informed speculation on stabilizing the market erode.

Further analysis of equation (3.8) indicates that there is a relationship between δ and ϵ. For a given value of ϵ, there is a value for δ (i.e. δ^*) that neutralizes the stabilizing (i.e. volatility reducing) effects of ϵ on lowering volatility. In other words, δ^* sets $ESPD_{WS} = ESPD_{NS}$.

$$\delta^* = \frac{-m+\sqrt{m^2+\epsilon^2(\alpha_H-\alpha_L)^2}}{(\alpha_H-\alpha_L)} \tag{3.9}$$

Equation (3.9) demonstrates that as the value of ϵ rises, the value of δ^* also rises. As the quality of information increases, it takes more and more bullishness by irrational speculators to neutralize the stabilizing effects of speculation by informed speculators.

There are three possible values for δ for any given value of ϵ:

1) $\delta < \delta^*$: in this case $ESPD_{WS} < ESPD_{NS}$
2) $\delta = \delta^*$: in this case $ESPD_{WS} = ESPD_{NS}$
3) $\delta > \delta^*$: in this case $ESPD_{WS} > ESPD_{NS}$

The three cases above indicate that the quality of information (ϵ) should be sufficiently high to counter the destabilizing effects the presence of irrational speculators.

The model presented in this section confirms Friedman's assertion that speculation leads to less price volatility, unless it is carried out by irrational (uninformed) speculators. The model indicates that the impact of uncertainty on price variability from one period to another is mitigated once information based speculation is introduced into the market. As discussed earlier, the futures market is a conveyer of information about the fundamentals in the spot market.

3.3 Summary

This chapter describes the theoretical model of this study. The model shows that speculation reduces price volatility unless it is carried out by speculators who do not act on information. The action of these irrational speculators counters the stabilizing effect of speculation based on information.

Higher quality of information leads to less price volatility and increases the level of misinformed speculation needed neutralize the stabilizing effect of speculation based on information.

Chapter 4: Econometrics

This chapter describes the econometric models used to test the theory that was discussed in chapter 3. It begins by describing the GARCH model, which is used to measure the rice price volatility before and after the introduction of the futures market on the CBOT. It then proceeds to specify vector autoregressive models (VAR) for the purposes of conducting the Granger Causality test and the impulse response function analysis. The latter two are performed to detect and measure any causality between futures trading activity and rice price volatility respectively[33]. Lastly, three detrending methods are proposed to capture sudden changes in futures trading activity.

4.1 Rice Cash Price Volatility

Generalized autoregressive conditional heteroskedasticity (GARCH) is used to model the volatility of the rice cash market in United States and the world. The GARCH model is commonly used when dealing with time series data. The use of GARCH as a model of volatility allows for the past shocks in the rice market to be included in the measure of current period volatility. More specifically, a GARCH (p,q) model would take the contribution from the lagged values of conditional variances into account (Bollerslev, 1986). Equation (4.3) represents a GARCH (p,q) model.

$$y_t = \alpha + \sum_{i=1}^{q} \beta_i y_{t-i} + \epsilon_t \quad (4.1)$$

$$h_t = a_\circ + \sum_{i=1}^{q} a_i \, \epsilon_{t-i}^2 \quad (4.2)$$[34]

$$h_t = a_\circ + \sum_{i=1}^{q} a_i \, \epsilon_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j} \quad (4.3)$$

[33] Forecast error variance decomposition (FEVD) analysis will also be carried out along with the impulse response function analysis

[34] Equation (4.2) represents the ARCH (Autoregressive Conditional Heteroskedasticity) process where the error variance is calculated only based on the lagged values of the error term.

y_t represents the return on the asset over a period of time. β_i is the coefficient on the past values of asset returns. Equation (4.1) indicates that the current value of the return depends on the past values of the return plus an error term, represented by ϵ_t which has a zero mean and a conditional variance of h_t. The error term may not necessarily have a constant variance, h_t over time. This is due to the effect of shocks as they carry over to other periods in a time series data before they completely subside.

The error variance in the GARCH model depends on past variance (persistence effect of past information, h_{t-j}) as well as exogenous shocks (new information, ϵ_{t-i}^2). A reduction in the value of b_j implies that news from previous periods has a less persistent effect on current price changes. Similarly, an increase in the value of a_i implies that prices absorb new information more rapidly.

This quality makes the GARCH model applicable to the analysis of the volatility of the rice cash market before and after the introduction of the futures market. It allows the change in cash price volatility in the rice market to be dissected into two major components with different implications. For example, an increase in rice cash price volatility after the introduction of the futures market could imply a more rapid absorption of information (larger value of a_i) by the market. Higher volatility could also indicate a higher persistence of the effect of past shocks and information (larger values of h_{t-j}) in the market. The latter case implies that the futures market is not playing its roles as a conveyer of information and a market price discovery tool (Holmes, 1996).

The GARCH model is widely used in measuring price volatility in commodities, as it is superior to other volatility measures such as the simple standard deviation or the weighted average of historical price variance. The drawback with these methods is that they do not distinguish between the predictable components of error variance, namely past error terms (h_{t-j})

and the unpredictable ones (ϵ_{t-i}^2) as GARCH does. In the GARCH model, price risk and forecast are determined simultaneously where price risk is specified as a function of variance of the errors of prices (Jayne & Myers, 1994). In addition, as inferred above, the GARCH model accounts for the time-varying pattern of price volatility (Yang, Haigh, & Leatham, 1992).

To model the impact of futures trading on the volatility of the cash price of rice the following regression is proposed:

$$r_t = \beta_o + \beta_1 CRB_t + \beta_2 WP_t + \epsilon_t \tag{4.4}$$

Where r_t is the log return of cash price for rice at time t, CRB_t and WP_t are the log returns of the proxy variables (more below), and ϵ_t is the error term in estimating the cash price return. It should be mentioned that log return refers to the log of the ratio of next period's price to the current one (i.e. $\log(\frac{P_{t+1}}{P_t})$)[35].

The use of proxy variables in the model allows the impact of market wide changes on rice cash price returns to be isolated, leaving the error term to explain the sources of change specific to the rice market. The proxy variables should be commodities for which there are no trading futures contracts (Antoniou & Foster, 1992) or the price of which is not affected by the introduction of the rice futures market. In 2010 finding a commodity without an established trading futures market is a tedious task. Instead, the return on CRB Reuters Commodity Index (CRB) is used.

CRB has been in existence since 1957 and provides a good reflection of the impact of shocks and new information in the commodity market in general[36]. Despite the fact that there have been futures trading on this index since 1986, similar studies have used it as a proxy variable in their models. It should also be noted that the values of r_t from previous periods (r_{t-i})

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[35] It should be noted that log return and return are used interchangeably in this study and both mean $\log(\frac{P_{t+1}}{P_t})$

[36] The composition of CRBR index is as follows: Oil & Natural Gas: 17.6%, Grains (wheat, corn, and soybean): 17.6%, Industrials: 11.8%, Meats: 11.8%, Softs: 23.5%, Precious metals: 17.6% (Reuters, 2010)

are not included in the model specified by equation (4.4). The proxy variables specified in equation (4.4) contains all the information that (r_{t-i}) do and more, because they reflect the state of the wider commodity market. In addition to the CRB Index, the use of log return of the world price of rice in equation (4.4) controls for the exogenous events that solely impact the rice market and not other commodities. The volatility in the world price of rice has not been influenced by the introduction of the rice futures market on the CBOT (as will be shown in chapter 5).

All literature reviewed for this work pointed to the presence of heteroskedasticity in the price returns of various commodities. Therefore, it is assumed that rice is not an exception. The error term in equation (4.4) is estimated using a GARCH(1,1) model (equation (4.6))

$$\epsilon_t = h_t z_t \tag{4.5}$$

$$h_t = a_0 + a_1 \epsilon_{t-1}^2 + b_1 h_{t-1} \tag{4.6}$$

Most of the previous work on commodity market volatility have chosen the GARCH(1,1) specification (Antoniou & Foster, 1992) and (Yang, Balyeat, & Leatham, 2005). The frequency of the data used in this work is monthly, a GARCH(1,1) model should be adequate to fully account for the effect of past news on current volatility[37].

The entire cash price series is divided into two sub series belonging to pre and post rice futures market. The GARCH(1,1) model is used to estimate the volatility for each period and then volatility results from each period are compared. In addition, the volatility of the entire price series is measured with a dummy variable in the GARCH model to account for the introduction of rice futures contract trading on CBOT in October 1994.

The significance of the coefficient on this dummy variable indicates whether the introduction of the futures market has affected cash price volatility or not. The rough rice price

[37] There are several alterations of the classic GARCH model. Appendix B provides a detailed theoretical explanation of one of these alternative models. Choosing GARCH(1,1) over the other methods allows for better comparison of results with previous studies on other commodities.

level is also included in the model to control for the level effect. Several works have concluded that there is less volatility at higher price levels. Reilly et al (1978) examined several stocks after a split and conclude that prices are significantly more volatile post split than before the split when prices were at a higher level (Reilly & Drzycimski, 1978). The general conclusion is that there is less volatility when prices rise and more when prices fall. Therefore the final equation modelling volatility in this work is[38]:

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t + \alpha_4 P_t \quad (4.7)$$

D takes the value of 0 to signify the era prior to the introduction of rice futures on the CBOT, and value of 1 for after. P is the price of rough rice (or milled rice when milled rice is examined).

The log return of the rice price was also tested for seasonality. The coefficients on the dummy variables representing each month of the year were insignificant with p-values higher than 0.05[39].

$$r_t = \gamma_1 D_1 + \gamma_2 D_2 + \gamma_3 D_3 + \gamma_4 D_4 + \gamma_5 D_5 + \gamma_6 D_6 + \gamma_7 D_7 + \gamma_8 D_8 + \gamma_9 D_9 + \gamma_{10} D_{10} + \gamma_{11} D_{11} + \gamma_{12} D_{12} \quad (4.8)$$

The joint null hypothesis failed to reject that $\gamma_i = 0$ (p-value = 0.06)[40]. The same method was applied to wheat price series and strong seasonality was detected with the joint test of the hypothesis strongly rejecting the null of $\gamma_i = 0$. Seasonal patterns in the price of wheat are well known and documented. Therefore, running the same regression as (4.8) with wheat price returns confirms validity of (4.8) in detecting the presence of seasonality in rough rice price returns. Seasonality test results are reported in Appendix D.

[38] Another form of this equation is presented in Appendix C. The equation in appendix C controls for the effect of previous periods' dummies on this period's volatility. However since the structural break occurres once in our model and is permanent with the same value, it was decided that both forms would yield approximately the same result, therefore the simpler one was chosen for this study.

[39] The coefficients for October and November were significant (p-values 0.033 and 0.003 respectively). However, given that the joint test was not significant, it was concluded that seasonality is not present in the series.

[40] The same test was applied to the rough rice futures price series and seasonality was also rejected for that series. The value of the joint test was 0.55

4.2 Vector Autoregressive Models (VARs)

There are three forms of VARs: reduced form, recursive form, and structural. This study will use the reduced form and recursive forms for the Granger causality test.

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \epsilon_t \tag{4.9}$$

$$TV_t = b_o + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + u_t \tag{4.10}$$

$$OI_t = c_o + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + v_t \tag{4.11}$$

Where σ_t is the rice cash price volatility, TV is the detrended rice futures contract trading volume, and OI is the detrended non-commercial open interest position in the rice futures contract. ϵ_t, u_t, v_t are the error terms. TV and OI are expressed in percentage form and have no units as will be discussed in section 4.3.

The concern with using the reduced form VAR is that the errors may be serially correlated. In order to address this problem, recursive VAR analysis is proposed. The recursive form VAR has the following structure:

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \varepsilon_t \tag{4.12}$$

$$TV_t = b_o + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + u_t \tag{4.13}$$

$$OI_t = c_o + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + \tau TV_t + v_t \tag{4.14}$$

$\epsilon_t, u_t, and\ v_t$ are uncorrelated. The inclusion of the current value of volatility (σ) in equation (4.13) removes any correlation between the error terms in equations (4.12) and (4.13). Therefore, the impact of the error in estimating equation (4.13) on the future value of volatility (σ) will only come from shocks to TV and not other variables in the system. The drawback with the recursive method is that the results depend on the ordering of variables (Stock & Watson, 2001). This work includes three variables in the VAR model. Therefore, the ordering of the variables will not alter the results significantly[41].

More recent literature has discussed the need to examine the level of trading activity in existing futures markets to understand their impact on cash price volatility. Granger causality test will be deployed to examine whether level of trading in the futures market causes changes in cash price volatility.

4.2.1 Granger Causality Test

The Granger causality test is used to determine whether past changes in variable X Granger cause (or explain) current changes in variable Y over and above past values of Y. Vector Autoregressive (VAR) techniques are used to carry out the Granger causality test. The first stage involves a regression in which variable Y is regressed on its own lagged values to determine how much of the current value of Y is explained by its lagged values. In the second stage lagged values of another variable (X) are included in the regression. If the lagged values of X have any explanatory power (i.e. statistically significant) then X is said to Granger cause Y.

The Granger causality test makes use of the following specification:

$$Y_t = \alpha_o + \sum_{i=1}^{p} \beta_i Y_{t-i} + \epsilon_t \qquad (4.15)$$

$$Y_t = \alpha_o + \sum_{i=1}^{p} \beta_i Y_{t-i} + \sum_{i=1}^{q} \gamma_i X_{t-i} + u_t \qquad (4.16)$$

X represents other factors that may Granger cause Y. ϵ_t and u_t are white noise residuals respectively.

The null hypothesis of the Granger Causality test indicates that:

$$\gamma_1 = \gamma_2 = \cdots = \gamma_q = 0 \qquad (4.17)$$

Therefore, failing to reject the null in the Granger causality test implies that X does not Granger cause Y.

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[41] Different ordering of variables mean that there will be six different combinations (n! Or 3!). The different combinations were examined but the results were similar as there are only three variables (Appendix E)

4.2.2 Impulse Response Function (IR)

Another advantage of the recursive VAR with uncorrelated errors is that it allows for an impulse response function analysis (IRF). The impact of one unit increase in error of estimating one of the variables on the current and future values of the other variables is purpose of the IR analysis.

Increasing v_t by one unit in equation (4.14) and having the ε_t and u_t from equations (4.12) and (4.13) constant allows one to observe the change in the current and future values of TV and σ. This indicates the impact that a unit increase in OI will have on $TV$and σ. The future horizon over which the impact is studied has to be chosen long enough so that the effect levels off or reverts to zero.

An important aspect of working with VAR models is the choice for the lag length of the variable in the model. The following part addresses this issue.

Akaike Information Criterion (AIC)

After determining the appropriate variables to be included in the VAR model (in this case detrended futures trading volume and open interest), one also has to specify the number of lags from each of those variable to be included in the model. Akaike Information Criterion (AIC) is chosen to determine the lag length for the VAR model in this study (Akaike, 1974).

$$AIC = 2\mathrm{T} - 2\ln(\mathrm{L}) \tag{4.18}$$

Where
T = number of parameters
L = value of likelihood function (maximized)

$$\ln L = ln\sqrt{\prod_{i=1}^{n}(\frac{1}{2\pi\sigma_i^2})} - \frac{1}{2}\sum_{i=1}^{n}\frac{(y_i - f(x))^2}{\sigma_i^2} \tag{4.19}$$

Where
y_i = actual observation
f(x) = estimated results
σ_i^2 = conditional variance

The lag length associated with the lowest AIC value will be included in the VAR model. Choosing the right lag order is important in rejecting or failing to reject the null hypothesis for Granger causality. Granger chose all lags for all variables to be equal (Granger, 1969). For larger number of variables in the model, Atukeren (2005) suggests another methodology to choose different lag for each variable. There is a description of this methodology in appendix F.

4.2.3 Forecast Error Variance Decomposition (FEVD)

Another method of studying the impact of a sudden change in either trading volume or open interest on cash price volatility is Forecast Error Variance Decomposition (FEVD). This method indicates the percentage of error made in forecasting a variable that is due to shocks in another variable in the recursive VAR model over a specified forecast horizon[42]. The FEVD method indicates how a shock to one variable contributes to the unpredictability of the other variable in the VAR model.

The IR analysis (described in 4.2.2) and FEVD point to the economic significance of a variable. These methods allow one to see the size of change in a variable caused by changes in another variable and not just whether the change is statistically significant or not (Abdullah & Rangazas, 1988). Therefore, variable A may fail the joint F-test of the Granger causality, indicating that it does cause changes in variable B, however variable A may explain a large percentage of the error variance when forecasting variable B. Therefore, it is important use the FEVD method as a supplement to the Granger Causality test to realize the magnitude of the effect of change in one variable on another.

[42] This study uses 100 steps ahead in order to have a long enough horizon. The effect of a current shock in one variable will have a long term impact on the error of forecasting another variable. This effect levels off after a few periods and becomes the long term effect. Therefore, in order to avoid the short term and intermediate fluctuations in the impact of shock to one variable on another, it is important to choose a long enough time horizon in this study to detect the long term impact of the shock to one variable (for example futures trading volume) on another variable (for example rice cash price volatility)

4.3 Detrending Futures Trading Volume and Open Interest

Level of futures trading is divided into two parts: trading volume and open interests. The goal of this section is to isolate the unexpected changes from long term trends in trading volume and open interests and estimate whether they cause changes in rice cash price volatility. The unexpected change in trading volume and open interest could be attributed to the sudden entrance of speculators into the futures market. The term speculation is referred to the activity of non-commercial interest in the rice market. Individuals whose sole purpose is to draw profits from the rice price fluctuations using futures contracts, without assuming position of any amount of rice.

In order to obtain the data pertaining to unexpected rise in trading volume and open interest, one has to detrend the data. The trading volume and open interest data of non-commercial interests has to be detrended to account for secular trends in trading volume and open interest numbers in the futures market[43]. Indeed both non-commercial open interest and trading volume demonstrate an increasing trend over time (Figures 10 and 11). Three detrending methods are proposed: one period percent change, polynomial of third degree, and centre moving average[44].

Percent Change (or First Difference Method-FD)

The percent change (represented by equation 4.20) of open interest and trading volume from one period to another is calculated. The Granger causality method tests whether change in percentage change of open interest or trading volume causes change in cash price volatility. The

[43] Unlike open interests the U.S. Commodity Futures Trading Commission does not provide non-commercial trading volume. This data could not be obtained from another source either. The detrending methods used in this study are adequate to ensure that only sudden momentary changes in the series are captured. General assumption of this study is that sudden changes in trading volume are attributable to the presence of non-commercial agents who are not normally present in the market. Therefore, lack of separate data on trading volume from non-commercial agents should not alter the results of this study.

[44] Please refer to the DATA section of this work for explanation on data selection.

advantage of using a one-period percent change is that one period change does not contain the long term trend in the time series.

$$\frac{X_t - X_{t-1}}{X_{t-1}} \quad (4.20)$$

X = Open interest or trading volume

Figure 12 demonstrates the trading volume and open interest data after be detrended by the first difference method.

Polynomial of Third Degree (P3)

This method takes into account of the possibility that open interest and trading volume may increase in a cubic function form (figures 10 and 11). The open interest or trading volume number is regressed on time in the following format:

$$X_{t_{est}} = \beta_0 + \beta_1 t + \beta_2 t^2 + \beta_3 t^3 + e_t \quad (4.21)$$

Where X = open interest or trading volume, t = time and e_t is the error term at time t. The difference between observed X and estimated X (i.e. e_t) is then divided by estimated X (i.e. $X_{t_{est}}$) to yield:

$$\frac{e_t}{X_{t\ est}} \quad (4.22)$$

The value of this ratio should be very close from one period to the next unless there are shocks to open interest and trading volume numbers during a period. Increase in the ratio for indicates a sudden jump in trading volume or open interest (figure 13). The Granger Causality method tests to determine whether change in the ratio specified by (4.22) causes a change in cash price volatility.

Centre Moving Average (CMA)

This method subtracts the current period trading volume or open interest from a five week average and then divides it by the average. The result clearly eliminates the long term trend in the data (figure 14)

$$\frac{X_t - average(X_{t-2}, X_{t-1}, X_t, X_{t+1}, X_{t+2})}{average(X_{t-2}, X_{t-1}, X_t, X_{t+1}, X_{t+2})} \quad (4.23)$$

Where is X is trading volume or open interest. The Granger Causality test analyzes the effect of change in the value of this ratio (i.e. 4.23) on cash price volatility.

The three detrending methods specified above, eliminate the long term trend in the data set used in this work (figures 12-14). The Granger causality test will be conducted using the detrended trading volume and non-commercial open interest from each of the methods specified above.

Detrended open interest and trading volume may Granger cause rice cash price volatility under one detrending method and not another. For example, trading volume may Granger cause cash price volatility after being detrended by the FD method and not cause volatility under P3 method. Therefore, a rule needs to be established for a final verdict (on whether sudden changes in trading volume and open interest Granger cause change in cash price volatility) while considering the results from the three detrending method.

In order for a sudden change in trading volume or/and open interest to Granger cause a significant change in cash price volatility two of the three detrending methods have to indicate so and at 5% level (i.e. P-values ≤ 0.05). This is referred to as the two-out-of-three rule.

4.4 Summary

Rice cash price volatility from before the introduction of the rice futures market is compared the one after. In addition, a dummy variable is introduced in the volatility model to mark the era of pre and post rice futures market. The significance of this dummy variable would be a strong indication that the presence of the futures market impacts cash price volatility.

GARCH(1,1) model is used to measure volatility and Vector Autoregressive models (VARs) are used to carry out the Granger Causality test, impulse response analysis, and forecast error variance decomposition.

In order to capture the sudden change in trading activity and to eliminate the long term trends in volume and open interest data, the two are detrended using three methods of rate of change (first difference-FD), third degree polynomial (P3), and centre moving average (CMA). The impact of trading activity on cash price volatility is measured three times, with one of these detrending methods being used each time. These detrending methods clearly removed the long term trend present in the open interest and trading volume data.

Chapter 5: Data and Results

This chapter is divided into two parts. The first part reveals the sources of data and the way they were used in the empirical analysis. The second part of this chapter offers an analysis of the results.

5.1 Data

The following sections describe the sources of the data that this study used to carry out the empirical analysis. In addition, they describe any operation done on the data series prior to use in the analysis.

5.1.1 Data Source

Two sets of prices are used as cash prices in our analysis. One is price of rough rice, which is the price received by farmers. The other is milled price of rice, which is the price received at milling stations by their operators. The volatility of the price of rough rice is the main focus of this study as it is underlying commodity of the rice futures contract on the CBOT. Both sets of prices are received from USDA's Rice Yearbook[45] (USDA, 2010).

The price for rough rice was available from September 1982 to February 2011 on a monthly basis. The milled rice prices were available from September 1979 to February 2010[46]. The futures contract trading volume data for rough rice is obtained from Datastream in a continuous stream format (Datastream, 2007)[47] and on a monthly basis[48]. Although rough rice

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[45] 2010 and earlier versions

[46] The 2010 version of rice yearbook only included prices up to February 2010. The price of rough rice from February 2010 to February 2011 was found in recent reports published by USDA (http://www.ers.usda.gov/briefing/rice/data.htm). However no such reports were found for milled rice

[47] Datastream provides a few continuous stream formats. The one that was chosen takes the closing price of the nearest contract. Once the delivery month is reached (on the first trading day of the delivery month), the data stream then switches over to the next nearest contract to obtain closing prices.

[48] Datastream provides trading volume data with daily and weekly frequencies. The monthly data is simply a sum of the daily trading volume

contracts were introduced to the CBOT in October 1994, the trading volume data were available only from February 2000.

Non-commercial open interest data were obtained from the U.S. Commodity Futures Trading Commission[49]. CRB Reuters Commodity Index numbers were obtained with monthly frequency from Datastream. The price of Thai 100% B second grade, which represents the world price of rice, was partially obtained from the Food and Agricultural Organization (F.A.O) International Commodity Price data base (please refer to 5.1.3 for more details)[50].

5.1.2 Cash Price Data

Milled rice prices are the average price of long grain no. 2 from three milling centres in United States (Louisiana, Arkansas, and Texas). Milled rice prices were divided into two sub series. The first series is from September 1979 to November September 1994. The second series is from October 1994 to February 2010. These two series fall before and after the introduction of the futures market on the CBOT and are equal in the number of observations.

The same process was applied to rough rice prices. They were divided into two series one spanning from September 1982 to September 1994 and the other from October 1994 to February 2011 (145 and 197 observations for each period respectively). The price data reported in USDA publications are expressed in US dollars/hundredweight (CWT). These figures are converted to metric tonne (1 cwt = 0.045352 tonnes).

5.1.3 World Prices

World rice prices (Thai 100% B second grade, Bangkok) are obtained from USDA rice year book from January 1960 to January 2010. From February 2010 to February 2011 prices are

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[49] http://www.cftc.gov/MarketReports/CommitmentsofTraders/HistoricalCompressed/index.htm
[50] http://www.fao.org/es/esc/prices/PricesServlet.jsp?lang=en

obtained from the Food and Agricultural Organization's (FAO) International Commodity Prices database[51]. The FAO database contains price data with weekly frequency.

The futures market in Zhengzhou was established in April 2009. Therefore, there were 104 weekly observations of world prices after the introduction of the futures market[52]. The volatility of this series was compared to 104 weekly world price observations from 2003 to 2005 signifying the period before the introduction of the rice futures market in Zhengzhou[53].

5.1.4 Open Interest Data

The non-commercial open interest data were available from October 1994 with weekly frequency, and were converted to monthly by taking the average of the open interest values of the four (or five) weekly data in each month. As indicated in 5.1.1, trading volume data were only available from February 2000, and therefore open interest data are also used from February 2000.

5.2 Results

This section presents and analyzes the results of the empirical analysis. It also offers an assessment of the empirical results in testing the theory that was presented in Chapter 3. In general the empirical results confirm the theory that the introduction of the futures market reduces cash price volatility.

5.2.1 Summary of Results

Results indicate that rice cash price volatility is lower after the introduction of the rice futures market. In addition, Granger Causality tests reveal that sudden changes in futures trading activity lead to higher volatility in cash prices. This indicates that the presence of irrational

[51] http://www.fao.org/es/esc/prices/PricesServlet.jsp?lang=en
[52] April 2009 to April 2011
[53] The era of 2007 to 2009, which would have been a natural choice for the period without the futures market was left out because of the crisis and the extraordinary circumstances in the rice market. Therefore, a random period that is far from this crisis and not too far from the realities of the current rice market was chosen.

speculators (represented by sudden and temporary changes in futures trading volume and open interest) leads to higher cash price volatility.

5.2.2 Has Speculation Reduced Cash Price Volatility of Rice?

The monthly cash price return variance, measured by the GARCH (1,1), is lower after the introduction of the futures market on the CBOT in October 1994. The average monthly log return variance of the price received by farmers (rough rice) from September 1982 to September 1994 was 0.0076, whereas from October 1994 to February 2011, the variance was 0.0019. This is also despite the world rice market crisis of 2007-2008. The results of the same analysis on milled rice prices indicated that the variance was higher in the period prior to the introduction of the futures market (0.0051 versus 0.0009).

Figures 15 to 18 demonstrate this higher volatility for both rough and milled rice during the period before the introduction of the rice futures market. Appendix G reports the monthly variance generated by the GARCH(1,1) model for both rough and milled rice.

Rough Rice Price Volatility

The estimation of equation 4.7 ($h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t + \alpha_4 P_t$) reveals that the coefficient on the dummy variable (α_3) is significant (p-value = 0.000) and the introduction of the rice futures market has reduced cash price volatility by about 51%. The coefficient on the price level (α_4) is also significant (p-value = 0.046) and confirms that an increase in price level lowers the volatility and vice versa by 0.5%. Therefore, controlling for the price level in the volatility model is important as price changes generate different magnitude of volatility at different price levels.

Estimation of equation 4.4 ($r_t = \beta_o + \beta_1 CRB_t + \beta_2 WP_t + \epsilon_t$) reveals that the monthly return on world price has a positive and significant effect on the price return of rough rice in Unite States (8.8% and p-value= 0.00). This result demonstrates the link between the world and

U.S. rice market and justifies controlling for the impact of return on world rice price on the US rough rice price. The coefficient on the CRB Index return was not significant (p-value = 0.64), which is an indication that wider commodity events in the world do not have a significant effect on rough rice price returns in Untied States. Table 1 summarizes the results discussed above.

The following equation was estimated separately for each period before and after the introduction of the rice futures market to compare the characteristics of the price volatility from each period. The purpose of this analysis is to see how sources and characteristics of volatility in the rough rice price change in the presence and absence of the rice futures market.

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 P_t \qquad (5.1)$$

It is interesting to note that none of the coefficients (α_1, α_2 and α_3) are significant in the period after the introduction of the futures market. This indicates that news from previous periods has a less persistent effect on current price changes and that prices absorb new information more rapidly. This confirms the earlier theoretical discussion about the effect of the futures market on increasing information flow, which seems to apply to the rice market in United States.

The coefficients in equation (5.1) were all significant when the analysis was done for the period prior to the introduction of the rice futures market (Table 2). This indicates that before the rice futures market, shocks were more persistent and took longer to show their full effect on the market.

In addition, price level effect discussed earlier was significant in the period prior to the futures market, whereas it was not after the introduction of the futures market. This result could be due to the fact that the futures market creates the possibility of hedging hence price level movement in either direction does not have as pronounced asymmetric effect as it would in the absence of the futures market.

The coefficient on the world price return is also significant and has positive effect on rough rice price return in United State before the rice futures market (unlike after the introduction of the futures market). The hedging effect made possible by the futures market perhaps makes the rough rice market in United States less susceptible to high volatility due to temporary shocks to the world rice market.

Milled Rice Price Volatility

This study is mainly concerned with the volatility of the price of rough rice. However, for reasons cited earlier, the volatility of milled rice prices are also investigated. The dummy variable specified by equation (4.7) was significant (p-value = 0.00) and indicated that the introduction of the futures market has led to a 47% reduction in the volatility of milled rice. As in the case of rough rice the world price returns also have a significant impact on the milled rice price returns (p-value = 0.00). However, unlike rough rice, milled rice price returns are linked with the CRB index return (p-value=0.02). Rice millers maybe more exposed the wider commodity spectrum where the prices of other commodities have a more direct impact on the price they charge than rice farmers. Table 3 summarizes the results of monthly volatility estimation for milled rice.

The volatility characteristics of milled rice price before and after the introduction of the futures market were compared by estimating equation (5.1). Table 4 presents a summary of the results. Change in world price return has a significant effect on the price return of milled rice both before and (unlike rough rice) after the introduction of the futures market. Also, change in price level has an impact on change in price volatility both before and after the futures market. The rice futures market seems to have had a more significant impact on the volatility of rough rice than milled rice. Perhaps this is expected given that the underlying rice futures contract is rough rice.

Rice Futures Market in China and Global Rice Price Volatility

The volatility of world rice prices prior to and after the introduction of rice futures market in Zhengzhou is measured using GARCH (1,1). Comparing the two volatility series shows that the weekly volatility is lower for most of the months in the period prior to the introduction of the futures (Figures 19 and 20). However, as statistics show (below), one cannot conclude that the world price is affected by the introduction of the rice futures in Zhengzahou. The coefficients of equation (5.3) are estimated to determine the volatility of the world price of rice:

$$r_t = \beta_o + \beta_1 CRB_t + \epsilon_t \tag{5.2}$$

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t \tag{5.3}$$

r_t is the world price return and CRB_t is the return on the CRB index. The CRB index controls for the events that affect the commodity markets and also have an impact on the world rice market. Therefore ϵ_t captures the shocks exclusive to the rice market[54]. The estimate of the coefficient on the dummy variable in equation (5.3) is not significant (p-value = 0.73). Therefore, one cannot claim that the newly established futures market in China has led to less volatility in world rice prices.

Rice Futures on the CBOT and Global Rice Price Volatility

The volatility of world rice prices prior to and after the introduction of rice futures market on the CBOT was measured using GARCH (1,1). Juxtaposing the two price series volatilities (January 1978 to September 1994 and October 1994 to April 2011) does not show a higher or lower volatility of world prices prior to or after the introduction of the rice futures market on the CBOT (Figures 21 and 22). The estimate of the coefficient (α_3) on the dummy variable in equation (5.3) is not significant (p-value = 0.24). Therefore, one cannot claim that the

[54] The CRB coefficient is significant (p-value =0.00) post establishment of rice futures market in Zhengzhou and not before. This could be due to the general volatility that commodity markets have been experiencing since 2006 and is continuing today. This condition did not exist prior to 2006, therefore the return on CRB index does not have a significant (p-value=0.56) explanatory power for the world rice price return. It should be noted that the pre Zhengzhou rice futures period spans from 2003 to 2005 in this study

establishment of the rice futures market on the CBOT has led to less volatility in world rice prices[55].

5.2.3 Have Irrational Speculators Increased Cash Price Volatility of Rice?

The impact of trading volume and open interest on cash price volatility at both farm level and after milling is analyzed. The results of the Granger Causality test indicate that change in detrended trading volume and non-commercial open interest Granger cause a positive change in the variance of the cash price return of rice at both farm (rough rice) and milled rice level. The results are significant with p-values of less than 0.05 for all three detrending methods in case of rough rice, and for P3 and CMA in case of milled rice (two-tailed joint test), hence satisfying the two-out-of-three rule that was established in 4.3. Table 5 reports the p-values of the two-tailed test for causality in the rough rice market.

The results of the IR analysis indicate that errors in estimating the changes in the values of volume and open interest do not have a large impact on predicting the future changes in cash price variance. One unit increase in error of estimating the change in the detrended trading volume only leads to a 0.06% (using the first difference detrending method) change in variance estimation of the cash price. This value was 0.03% and 0.07% when the same analysis was done with P3 and CMA as detrending methods respectively.

One unit increase in error of estimating the change in the detrended open interest leads to 0.1%, 0.08%, and 0.1% change in variance estimation of the cash price when deploying FD, P3, and CMA methods respectively. The results of the IR analysis indicate that sudden changes in detrended volume and open interest do not have a significant (not statistically speaking) on the change in the volatility of the cash price at the farm level.

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[55] Appendix I offers a brief discussion on the correlation between the price of rough rice in United States and the world before and after the introduction of the rice futures market on the CBOT. This could shed further light on the impact that the introduction of this market may have had on the way the US rice market interacts with the world rice market.

The error in estimating changes in rice futures trading volume and open interest using their lagged values explained more (although not significatnly more) of the change in the volatility of the price of milled rice than rough rice. One unit increase in the trading volume error leads to a 0.3%, 0.03%, and -0.5% change in the volatility of the milled rice price using FD, P3, and CMA methods respectively[56]. These values are 0.02%, 0.4%, and 0.9% for open interest for each of the methods specified above (these figures are summarized in Table 6).

The futures trading volume and non-commercial open interest seem to have a larger impact on the price volatility of milled rice than rough rice. Indeed studying the correlation between the change in rough rice and futures price, and milled rice and futures price reveals that the futures price is more correlated with milled than rough rice (Table 7)[57]. This could partially explain why futures trading activity has a larger impact on milled rice price volatility in the IR analysis.

The results of the FEVD analysis paint a different picture than those from the IR analysis. In the case of rough rice, sudden changes in trading volume contributes 3.3%, 2.3%, (using FD and P3 detrending methods) and 2.7% (using CMA detrending method) to the error in forecasting the volatility of the rough rice price. Therefore, it could be concluded that sudden changes in trading volume does not have a significant (not in statistical sense) impact on the rough rice price volatility. In case of non-commercial open interest these values were 18.9%, 15.2%, and 7.4%. Therefore, shocks to futures open interest numbers contribute significantly (in an economic sense) to the error in forecasting rough rice price volatility.

In case of milled rice, shocks to trading volume have a larger contribution to changes in price volatility than rough rice. Using the three detrending methods specified earlier, a shock to

[56] The negative value (-0.5%) obtained from the CMA detrending method indicates that positive sudden change in futures trading volume could lead to a decrease in volatility. However, given that this figure is small and that the other two numbers from FD and P3 methods (two-out-of-three rule) are positive, this negative value is ignored

[57] The results from the P3 method should be viewed with skepticism as all three values generated by this method are the highest and far off the other two values

trading volume number leads to 3.8%, 6.2%, and 9.5% (FD, P3, CMA respectively) change in milled price volatility. The values of these shocks were 0.1%, 7.8%, and 3.0% in case of open interest. The results are summarized in Table 8.

The results above indicate that shocks to futures open interest have a larger impact on rough rice (farm) price volatility than trading volume. Change in non-commercial open interest numbers could be a signal to farmers that speculators are anticipating higher or lower prices in the future and hence farmers allocate their harvest accordingly. For instance, a surge in the number of non-commercial short positions could be a signal prices will fall in the future. Farmers[58] may decide to sell all they can today (including what they store) as they perceive today's prices to be higher than tomorrow. This surge in supply in the market, while lowering the price that farmers receive, could also lead to higher volatility.

Shocks to futures trading volume seem to have a larger impact on milled rice price volatility than rough rice according to the FEVD analysis. Milling operations could be more engaged in the trading of the rice futures contracts than farmers. They are constantly buying and selling the physical rice stocks (they do not wait for harvest etc.). Therefore, sudden changes in rice futures trading volume which reflects the temporary conditions in the rice market affects rice millers more than rice farmers. Higher futures trading volume and the presence of more (irrational) speculators may be inviting for rice millers to adjust the price of milled rice to take advantage of the temporary market conditions, leading to higher volatility in the price milled rice[59].

5.3 Summary

The rice market seems to be less volatile after the introduction of the rice futures market on the CBOT, hence confirming the theory presented in chapter 3. In addition, the tests reveal

[58] or other agents who carry rice inventories
[59] Stata output for section 5.2 is available in appendix J

that sudden increase in rice futures trading activity, which is a proxy for the presence of irrational speculators, causes higher rice cash price volatility.

The cash price of rice shows more volatility prior to the introduction of the rice futures market on the CBOT than afterwards. The dummy variable, which distinguishes the pre and post futures periods in the GARCH(1,1) volatility equation, is significant. The same analysis on the impact of the introduction of the rice futures market in China produced insignificant results.

Sudden change in trading activity which is a proxy for the presence of irrational speculators in the market Granger caused the cash price volatility (farm and milled prices). The IR analysis indicated that a change in detrended open interest or trading volume data has a minor effect on cash price volatility of rough rice. These effects are more pronounced when the same analysis is carried out using milled rice prices. The FEVD method indicates that sudden changes in futures trading volume affect the volatility of milled rice prices more than rough rice prices. The reverse is true when the impact of temporary shocks to non-commercial open interest on milled and rough rice price volatility is examined.

The Granger Causality test indicates that the trading activity in the rice futures market has a significant impact on cash price volatility of rice. However, this should be viewed with caution as Granger Causality points to statistical significance of the results. The magnitude of this impact, measured by IR and FEVD methods, indicates that the price volatility of rough rice is not affected by futures trading volume as much as milled rice. This could be attributed to the higher correlation between milled rice and futures price than rough rice and futures price. However, sudden change to futures open interest had a higher impact on rough rice price volatility than milled rice. Perhaps better understanding of the structure of rice market in United States could shed more light on this matter, and why open interest matters more to rough rice price volatility than milled rice price volatility

Chapter 6: Conclusion

This work presents and tests Friedman's original statement that speculators stabilize the market (reduce price volatility) unless they are irrational. The first part of this theory asserts that the presence of speculators in the market and better foresight about the future price of the commodity does lead to less volatility. The second part indicates that only the presence of irrational (uninformed) speculators lead to increase price volatility.

This study proposes the use of the futures market as a proxy for the presence of speculators in the market. Sudden changes in futures trading activity figures such as trading volume and open interest is set as a proxy for the presence of irrational speculators.

The rice futures market on the CBOT is chosen for this project. Rice is an important staple food for about half the world's population, yet it does not have a viable global market like wheat and maize. The intention is that the empirical testing of the impact on speculation on price volatility using the rice futures market could provide a direction for further research in forming a more functional and less volatile global rice market.

Based on the results of the empirical analysis, the introduction of rice futures market has led to lower cash price volatility in the rice market in United States. This indicates that the presence of speculators with enhanced foresight through futures market has led to more stability in the rice market in United States. GARCH(1,1) model was used to measure the volatility of rice prices. In addition, a dummy variable was added to the GARCH(1,1) model to separate the two periods of pre and post introduction of rice futures market on the CBOT.

Using the Granger Causality method, modeled by a recursive VAR reveals that trading activity in the futures market increases cash price volatility. However, Granger Causality test only points out the statistical significance of one variable explaining another. FEVD and IR analysis are proposed to measure the effect of futures trading activity on cash price volatility.

The latter tests reveal that a sudden change in trading volume and open interest lead to higher degree of volatility in the cash price of milled rice than rough rice (farm price). Sudden entrance of speculators in the futures market destabilizes the rice cash market. However, understanding the market for a commodity is important in determining where this irrational speculative presence is most destabilizing.

This study could be applied to another more global rice futures market in the future to assess its impact on world price volatility. The same assessment in this work revealed no impact on world prices by rice futures market on the CBOT. Future research could focus more directly on how a viable global rice futures market and private speculative presence in that market could lead to more stability in world rice prices.

6.1 Limitations

The more prominent impact of rice futures trading activity on the volatility of milled rice prices may be an indication that rice milling operators use the futures market more than farmers. However, data on futures trading and open interest do not distinguish between the two. Therefore, obtaining separate data on farmer's and milling operators' activities in the futures market could shed light on the reason for the different degree of interaction between rough rice (farm), milled rice, and rice futures market.

The thinness of trade in the rice market, illiquidity in futures market and a relatively low number of monthly observations make it an inherently volatile market in terms of trading activity. As a result the rice futures market may not be a good proxy for the presence of speculation in the market to test the theory put forward in chapter 3. However, the importance of rice as a global staple food makes the current study using the rice futures market relevant. Never the less, these results should be revisited a few years from now once there is longer time series on rice futures trading activity and when the rice futures market is more active.

Tables

Table 1: Rough Rice Price Volatility Estimation (equations 4.4 and 4.7) 1982-2011

β_o	β_1	β_2	$\alpha_\circ$	α_1	α_2	α_3	α_4
0.0089	0.0352	0.0890	-5.8528	0.4226	0.3277	-0.5124	-0.0050
0.76	0.64	0.00	0.00	0.00	0.00	0.00	0.05

*note: last row report the p-value

Table 2: Rough Rice Price Volatility before and after CBOT Rice Futures Market 1982-Sep1994 and Oct 1994-2011 (equation 5.1)[60]

	β_o	β_1	β_2	$\alpha_\circ$	α_1	α_2	α_3
1982-Sep94	-0.0146	0.0306	0.2338	-0.0682	0.2401	0.5111	-0.0472
p-value	0.67	0.84	0.00	0.92	0.02	0.00	0.00
Oct94-2011	0.0007	0.0679	0.0784	-7.5920	0.2230	0.4786	0.0007
p-value	0.83	0.48	0.14	0.00	0.09	0.06	0.76

Table 3: Milled Rice Price Volatility Estimation (equations 4.4 and 4.7) 1979-2010

β_o	β_1	β_2	$\alpha_\circ$	α_1	α_2	α_3	α_4
-0.0103	0.1298	0.0821	-7.7117	1.1916	0.0042	-0.4716	0.0012
0.00	0.02	0.00	0.00	0.00	0.85	0.00	0.10

*note: last row report the p-value

Table 4: Milled Rice Price Volatility before and after Futures Market 1979-Sep1994 and Oct1994-2007*(equation 5.1)[61]

	β_o	β_1	β_2	$\alpha_\circ$	α_1	α_2	α_3
1979-Sep94	-0.0014	0.1213	0.1724	-0.2889	0.8998	0.3776	-0.0239
p-value	0.34	0.06	0.00	0.84	0.00	0.00	0.00
Oct94-2007	-0.0020	0.1532	0.1201	-4.9863	0.0143	0.9494	-0.0180
p-value	0.35	0.10	0.00	0.00	0.21	0.00	0.013

*note: Stata encountered problems estimating the GARCH(1,1) with data running to 2010 for the post futures period. Therefore, data series to study the post futures for milled rice were chosen to December 2007

[60] Stata results of estimating equations (4.4), (4.7) and (5.1) are presented in Appendix H
[61] Stata results of estimating equations (4.4), (4.7) and (5.1) are presented in Appendix H

Table 5: Impact of Trading Activity on Cash Price Volatility: Granger Causality

Detrending Method	TV→ σ	OI → σ	TV& OI → σ (Joint Test)
FD	0.078	0.000	0.001
P3	0.399	0.002	0.006
CMA	0.068	0.012	0.003

*note: → signifies direction of causality.
TV → σ change in trading volume (TV) Granger causes cash price volatility
OI → σ change in open interest (OI) Granger causes cash price volatility

Table 6: Impact of Trading Activity on Cash Price Volatility: IR Analysis

	Rough Rice		Milled Rice	
Detrending Method	Open Interest	Trading Volume	Open Interest	Trading Volume
FD	0.1%	0.06%	0.02%	0.3%
P3	0.08%	0.03%	0.4%	0.03%
CMA	0.1%	0.07%	0.9%	-0.5%

Table 7: Correlation between Detrended Price Change in Milled, Rough and Futures Rice Price

Detrending Method	Futures-Rough	Futures-Milled	Rough-Milled
FD	0.18	0.33	0.57
P3	0.80	0.81	0.85
CMA	0.0007	0.13	0.42

Note: Price series is from February 2000 to February 2010

Table 8: Impact of Trading Activity on Cash Price Volatility: FEVD Analysis

	Rough Rice		Milled Rice	
Detrending Method	Open Interest	Trading Volume	Open Interest	Trading Volume
FD	18.9%	3.3%	0.1%	3.8%
P3	15.2%	2.3%	7.8%	6.2%
CMA	7.4%	2.7%	3.0%	9.5%

Figures

Figure 1: Speculator with Perfect Foresight

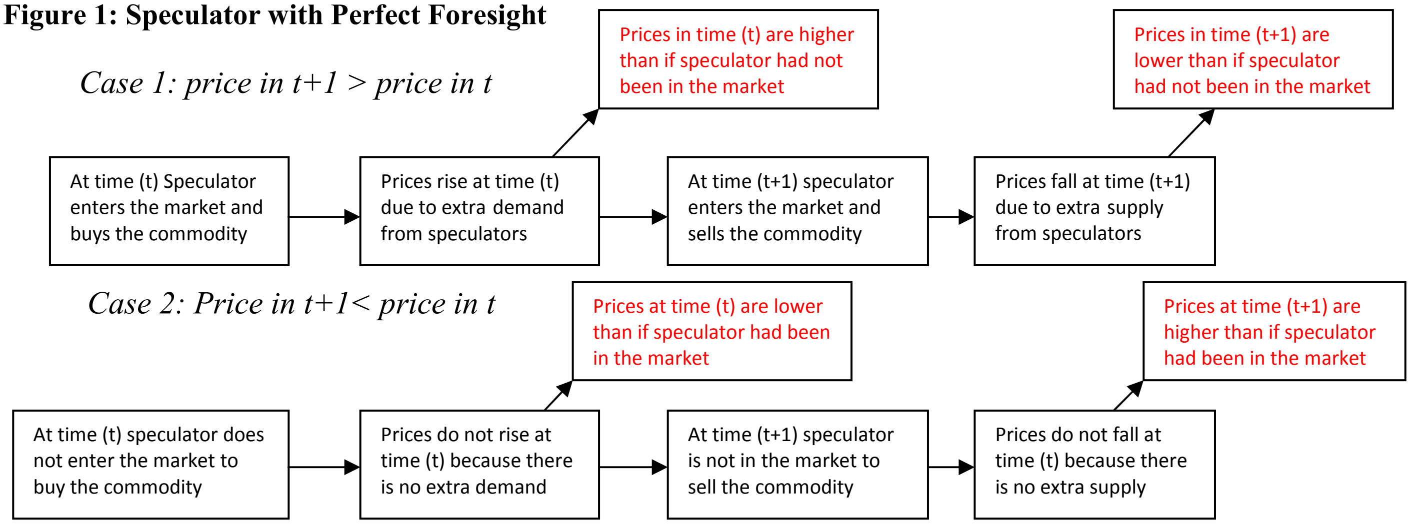
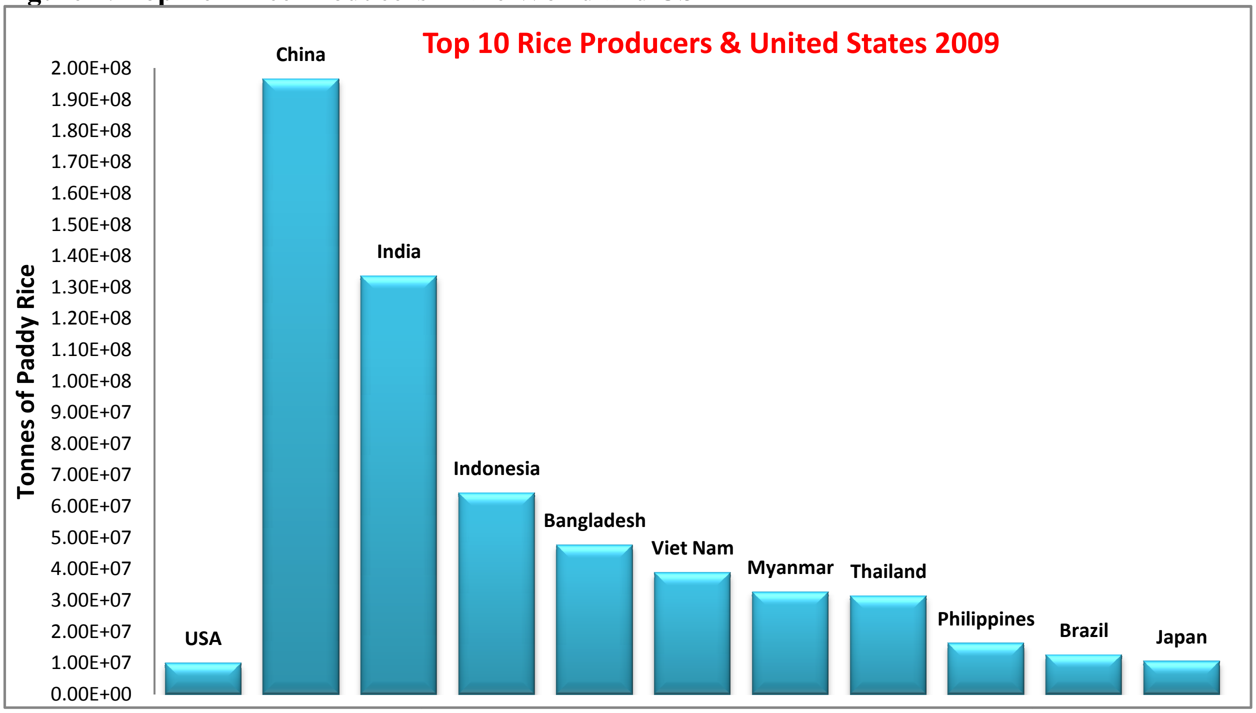
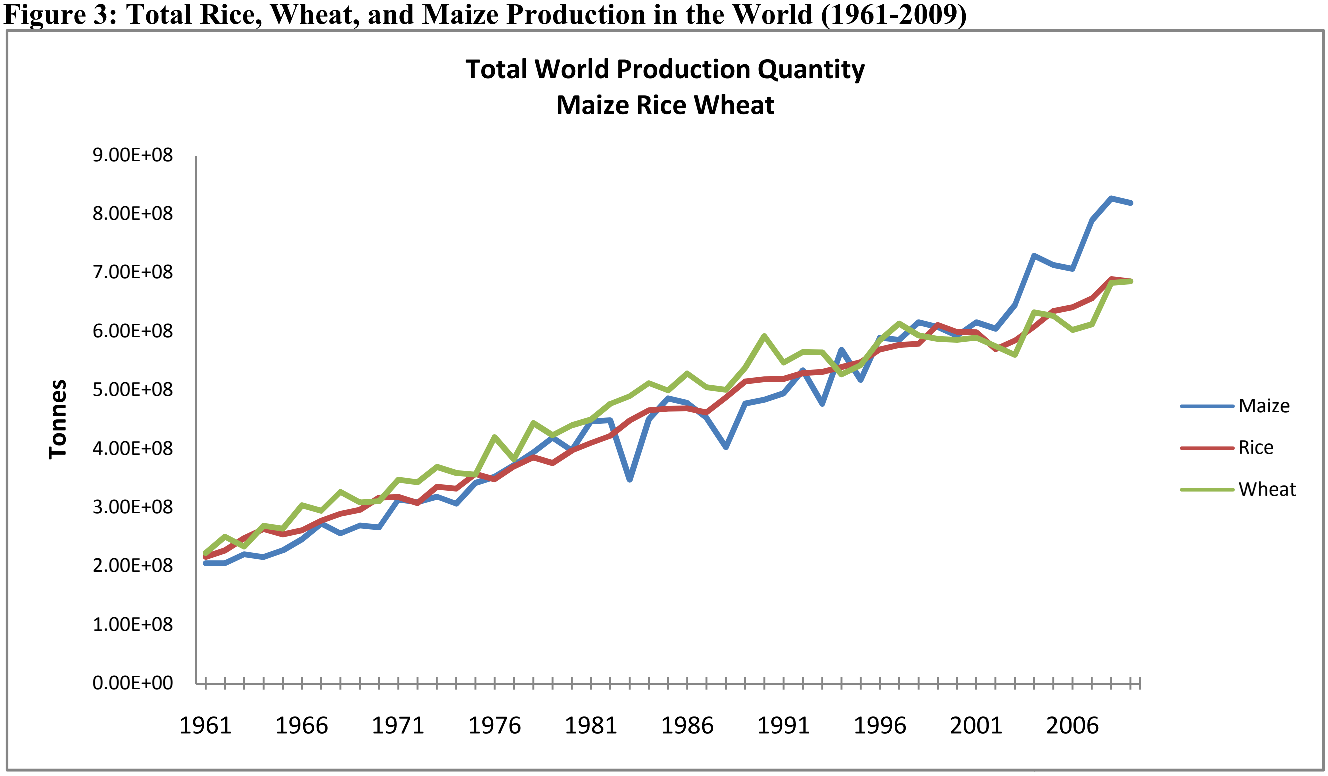


Figure 2: Top Ten Rice Producers in the World and USA



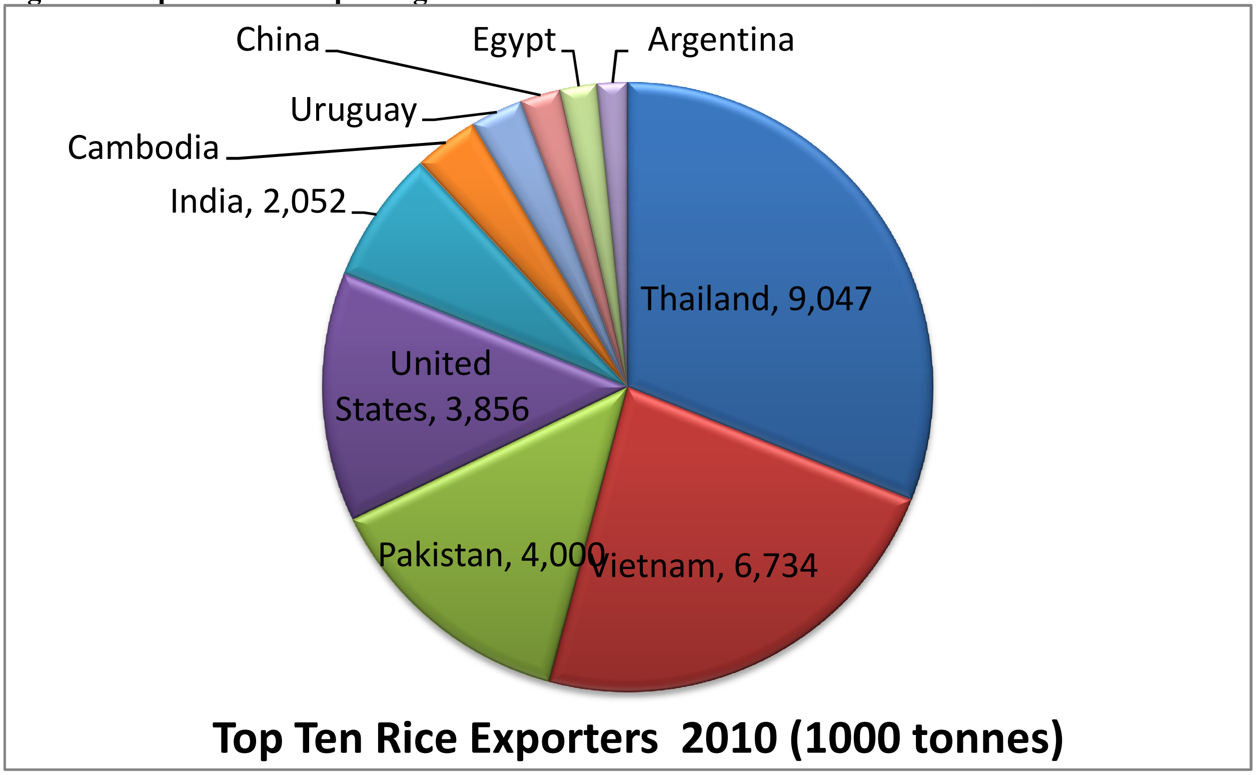
Data Source: FAOSTAT (2009) Production/Crops

Figure 3: Total Rice, Wheat, and Maize Production in the World (1961-2009)



Data Source: FAOSTAT (2009) Production/Crops

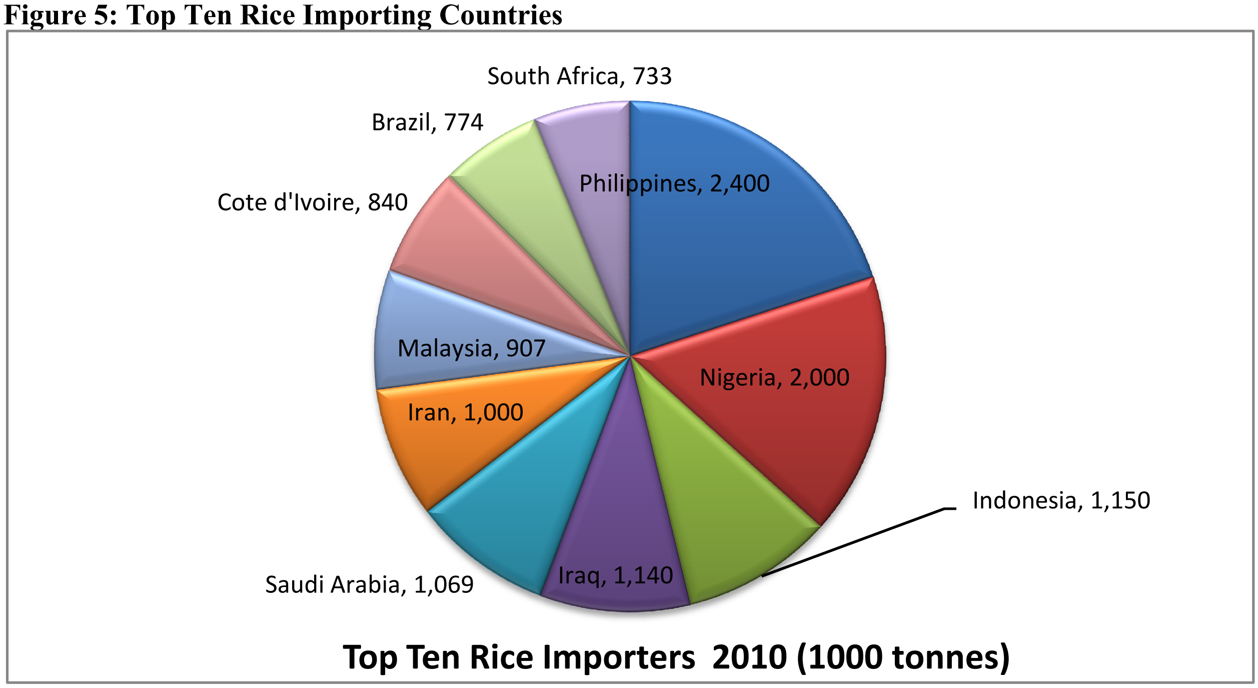
Figure 4: Top Ten Rice Exporting Countries



Note: figures are tonnes of rice (milled equivalent)

Data Source: USDA Rice Yearbook (2011) Table 23

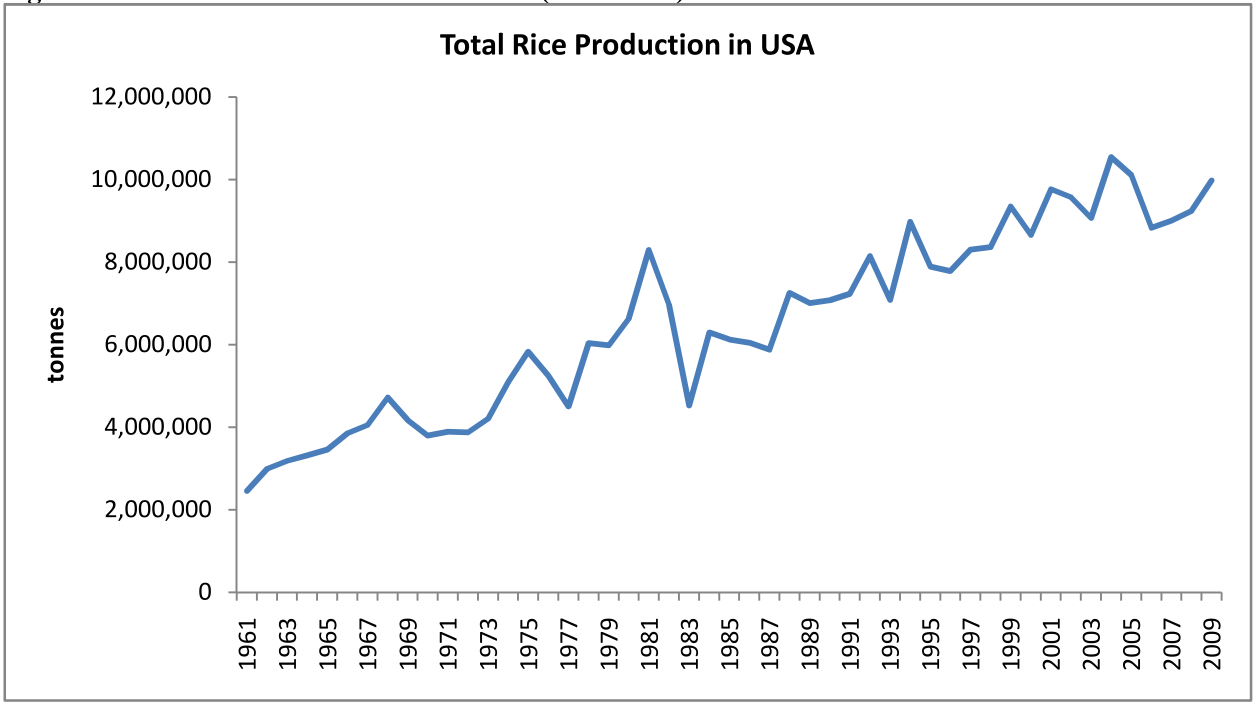
Figure 5: Top Ten Rice Importing Countries



Note: figures are tonnes of rice (milled equivalent)

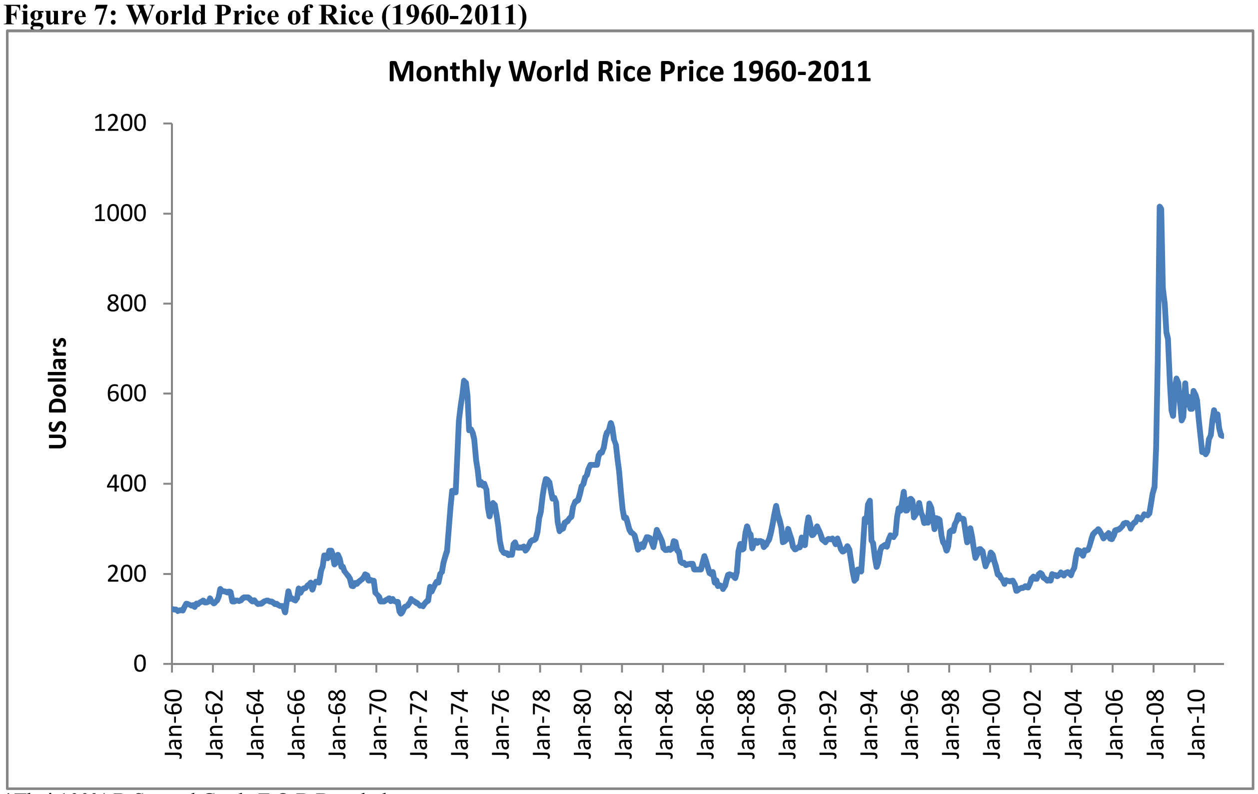
Data Source: USDA Rice Yearbook (2011) Table 23

Figure 6: Rice Production in United States (1961-2009)



Data Source: FAOSTAT (2009) Production/Crops

Figure 7: World Price of Rice (1960-2011)



*Thai 100% B Second Grade F.O.B Bangkok

Data Source: USDA Rice Yearbook Table 20 and Food and Agricultural Organization (F.A.O) International Commodity Price data base

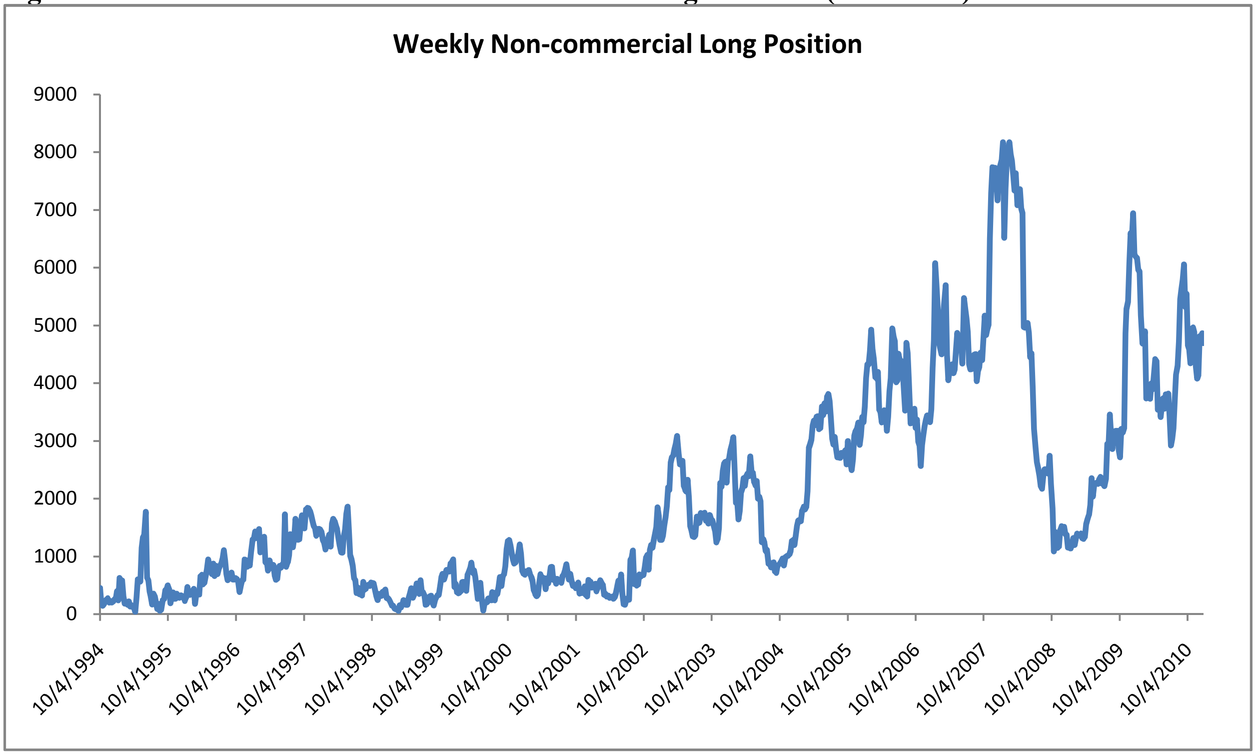
Figure 8: Rough Rice Futures Contract Specification

Source: Chicago Mercantile Exchange (CME Group)

http://www.cmegroup.com/trading/agricultural/grain-and-oilseed/rough-rice_contract_specifications.html

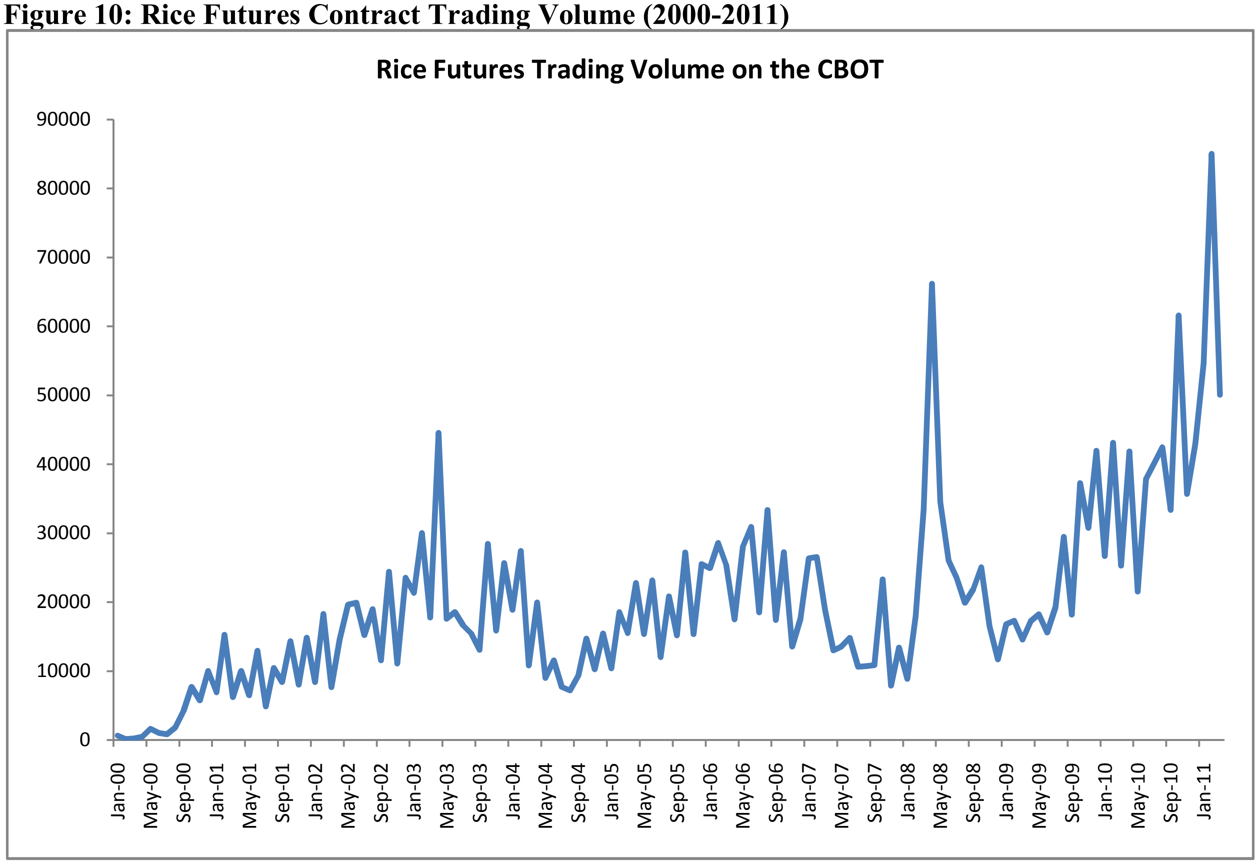
Contract Size	2,000 hundredweights (CWT) (~ 91 Metric Tons)	
Deliverable Grade	U.S. No. 2 or better long grain rough rice with a total milling yield of not less than 65% including head rice of not less than 48%. Premiums and discounts are provided for each percent of head rice over or below 55%, and for each percent of broken rice over or below 15%. No heat-damaged kernels are permitted in a 500-gram sample and no stained kernels are permitted in a 500-gram sample. A maximum of 75 lightly discolored kernels are permitted in a 500-gram sample.	
Pricing Unit	Cents per hundredweight	
Tick Size (minimum fluctuation)	1/2 cent per hundredweight ($10.00 per contract)	
Contract Months/Symbols	January (F), March (H), May (K), July (N), September (U) & November (X)	
Trading Hours	CME Globex (Electronic Platform)	6:00 pm - 7:15 am and 9:30 am - 1:15 pm Central Time, Sunday - Friday
	Open Outcry (Trading Floor)	9:30 am - 1:15 pm Central Time, Monday - Friday
Daily Price Limit	$0.50 per hundredweight expandable to $0.75 and then to $1.15 when the market closes at limit bid or limit offer. There shall be no price limits on the current month contract on or after the second business day preceding the first day of the delivery month.	
Settlement Procedure	Physical Delivery	
Last Trade Date	The business day prior to the 15th calendar day of the contract month.	
Last Delivery Date	Seventh business day following the last trading day of the month.	
Product Ticker Symbols	CME Globex (Electronic Platform)	ZR 14=Clearing
	Open Outcry (Trading Floor)	RR
Exchange Rule	These contracts are listed with, and subject to, the rules and regulations of CBOT.	

Figure 9: Total non-commercial Futures Contract Long Positions (1994-2010)



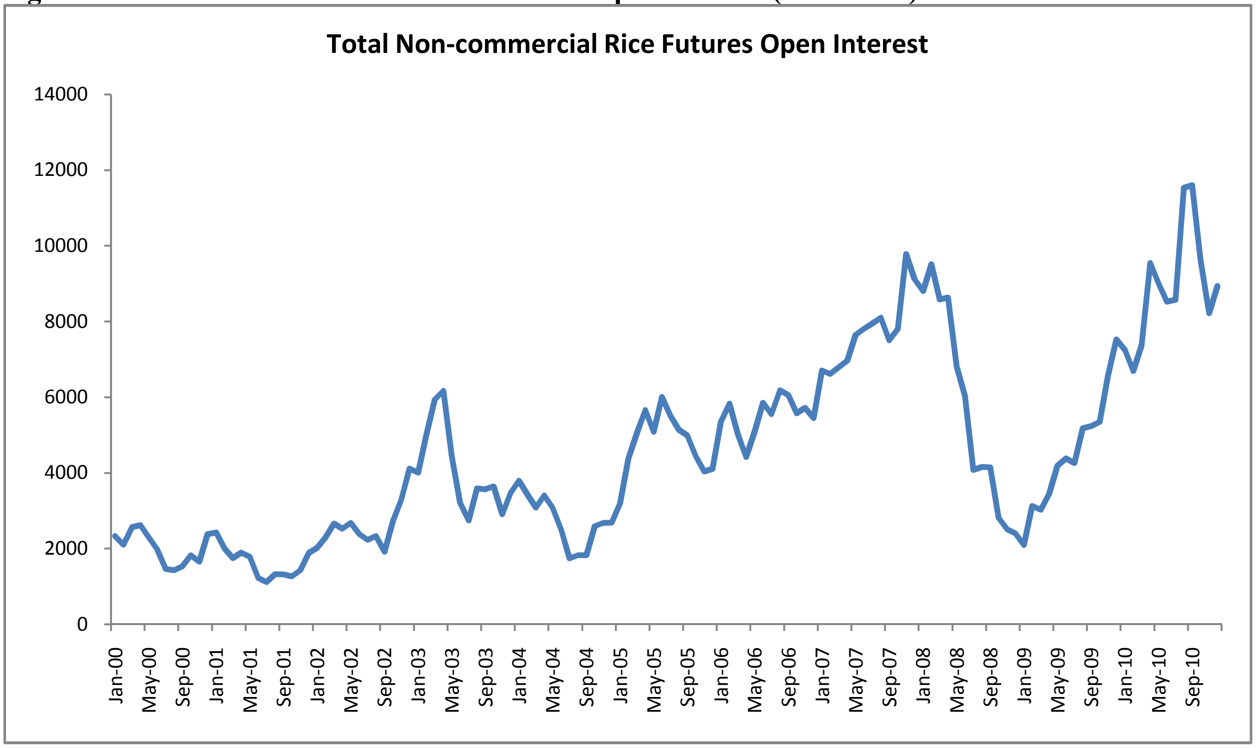
Data Source: US Commodity Futures Trading Commission

Figure 10: Rice Futures Contract Trading Volume (2000-2011)



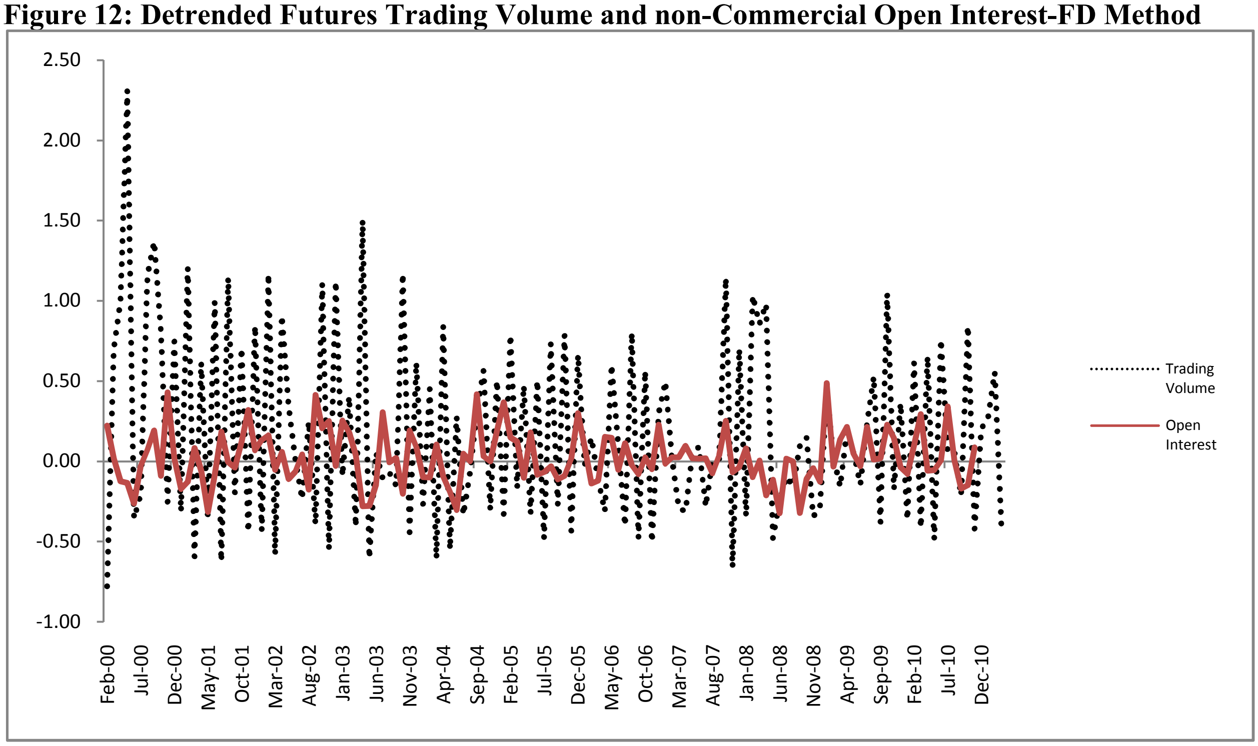
Data Source: Reuters Datastream CBOT Rough Rice Futures Trade Data

Figure 11: Total non-commercial Rice Futures Open Interest (2000-2010)



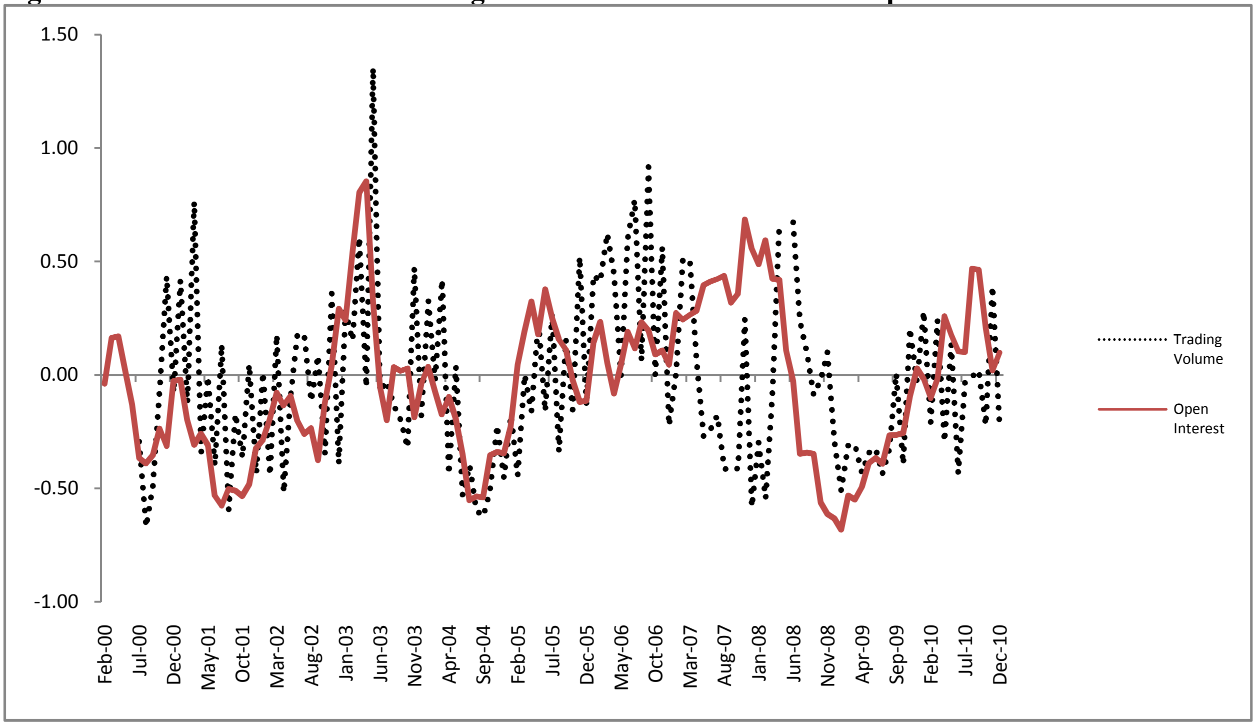
Data Source: US Commodity Futures Trading Commission

Figure 12: Detrended Futures Trading Volume and non-Commercial Open Interest-FD Method



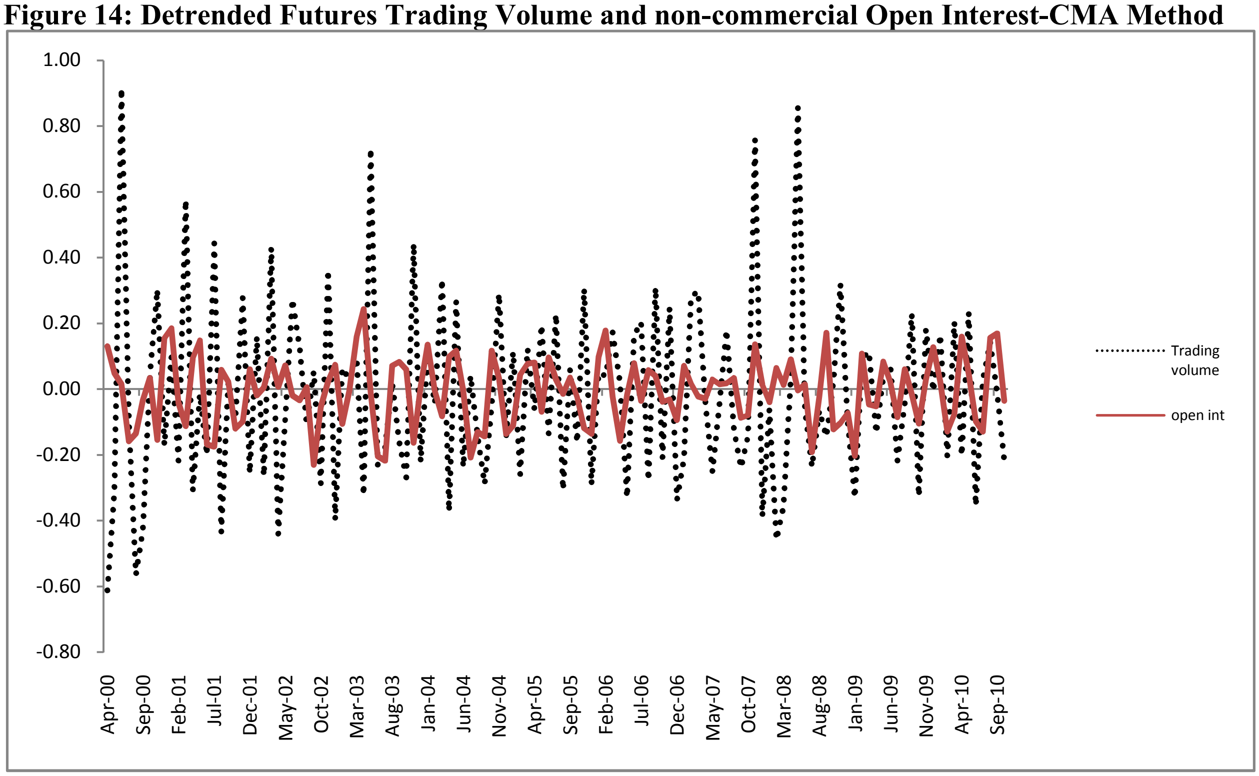
Data Source: Datastream and US Commodity Futures Trading Commission

Figure 13: Detrended Futures Trading Volume and non-commercial Open Interest-P3 Method



Data Source: Datastream and US Commodity Futures Trading Commission

Figure 14: Detrended Futures Trading Volume and non-commercial Open Interest-CMA Method



Data Source: Datastream and US Commodity Futures Trading Commission

Figure 15: Rough Rice Price Return Variance (GARCH) pre Futures

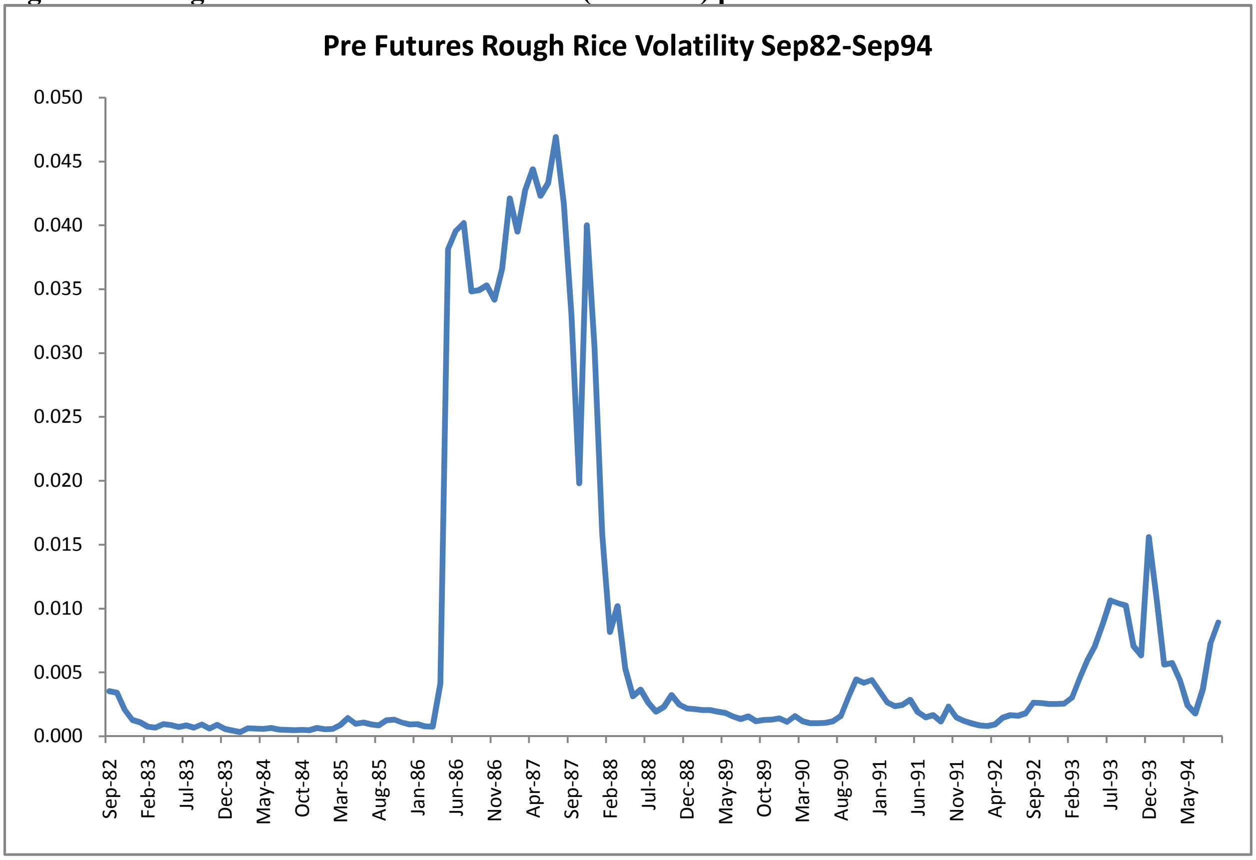


Figure 16: Rough Rice Price Return Variance (GARCH) post Futures

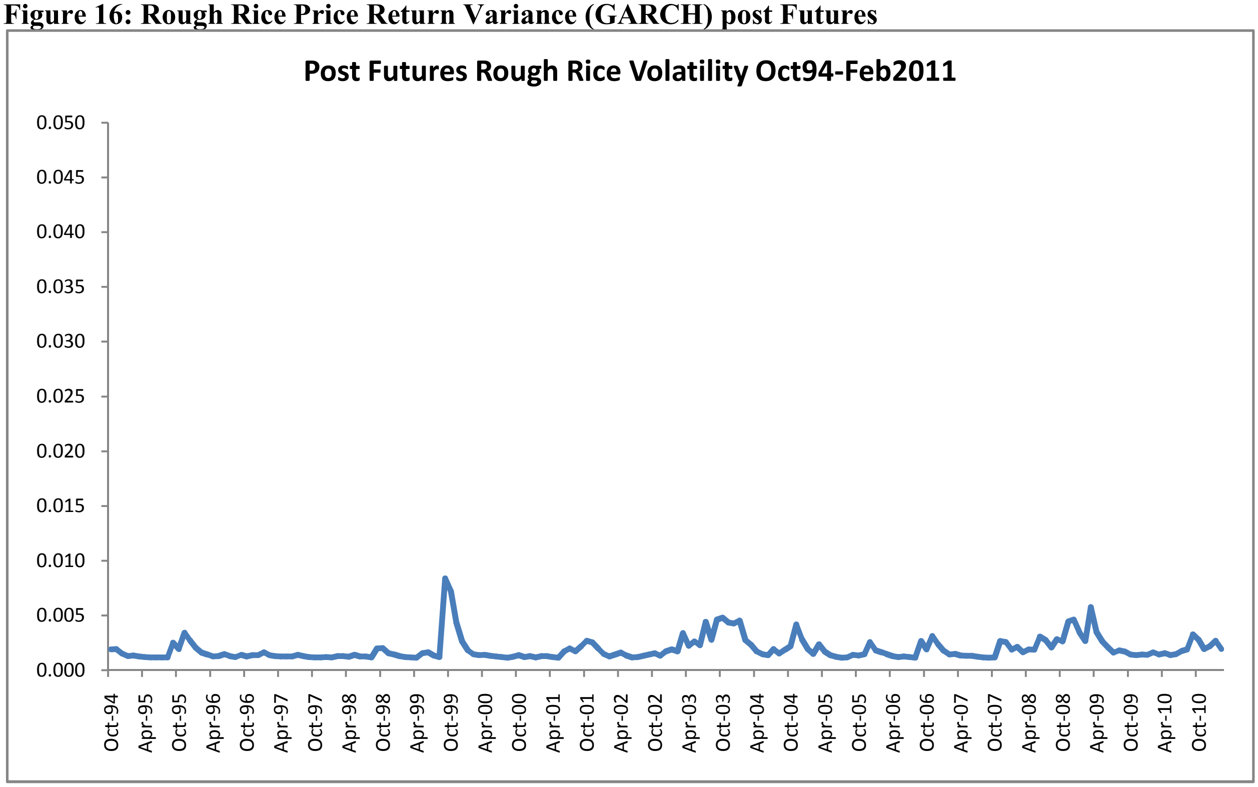


Figure 17: Milled Rice Price Return Variance (GARCH) pre Futures

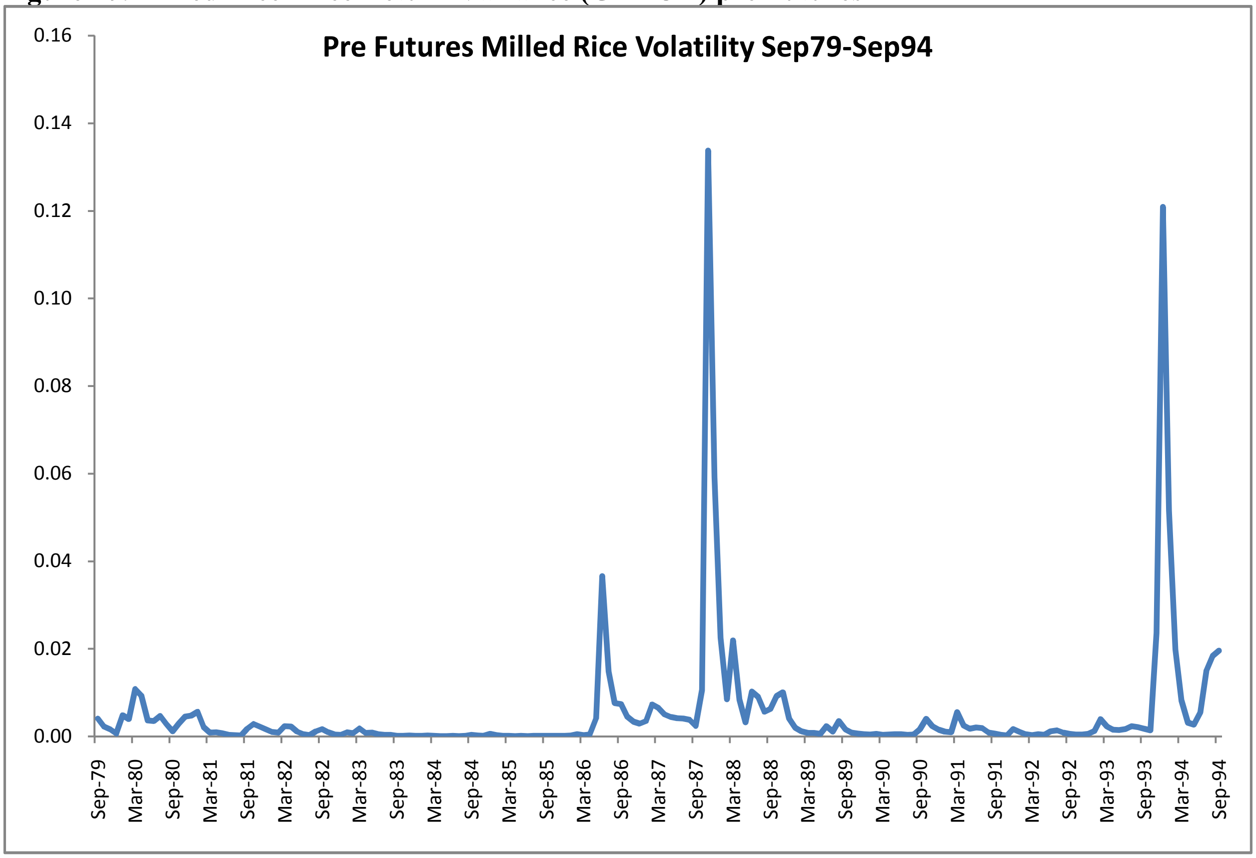


Figure 18: Milled Rice Price Return Variance (GARCH) post Futures

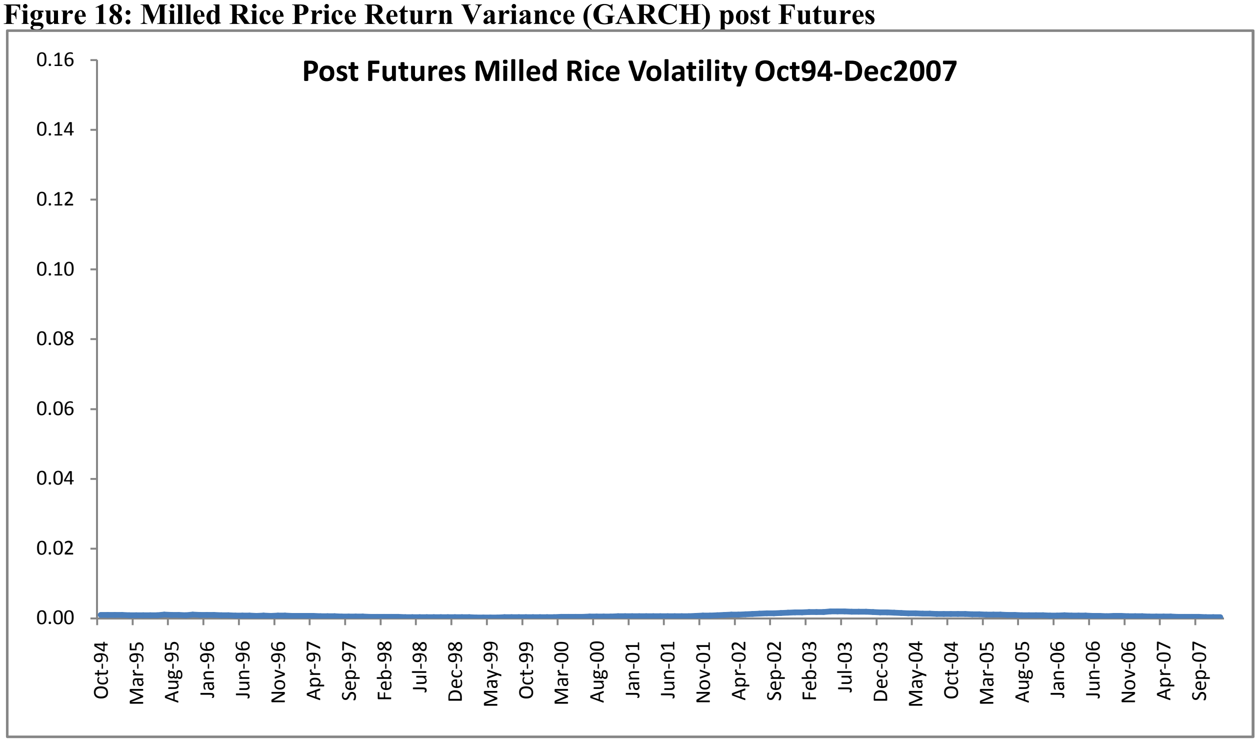


Figure 19: World Rice Price Volatility pre Zhengzhou Rice Futures Market

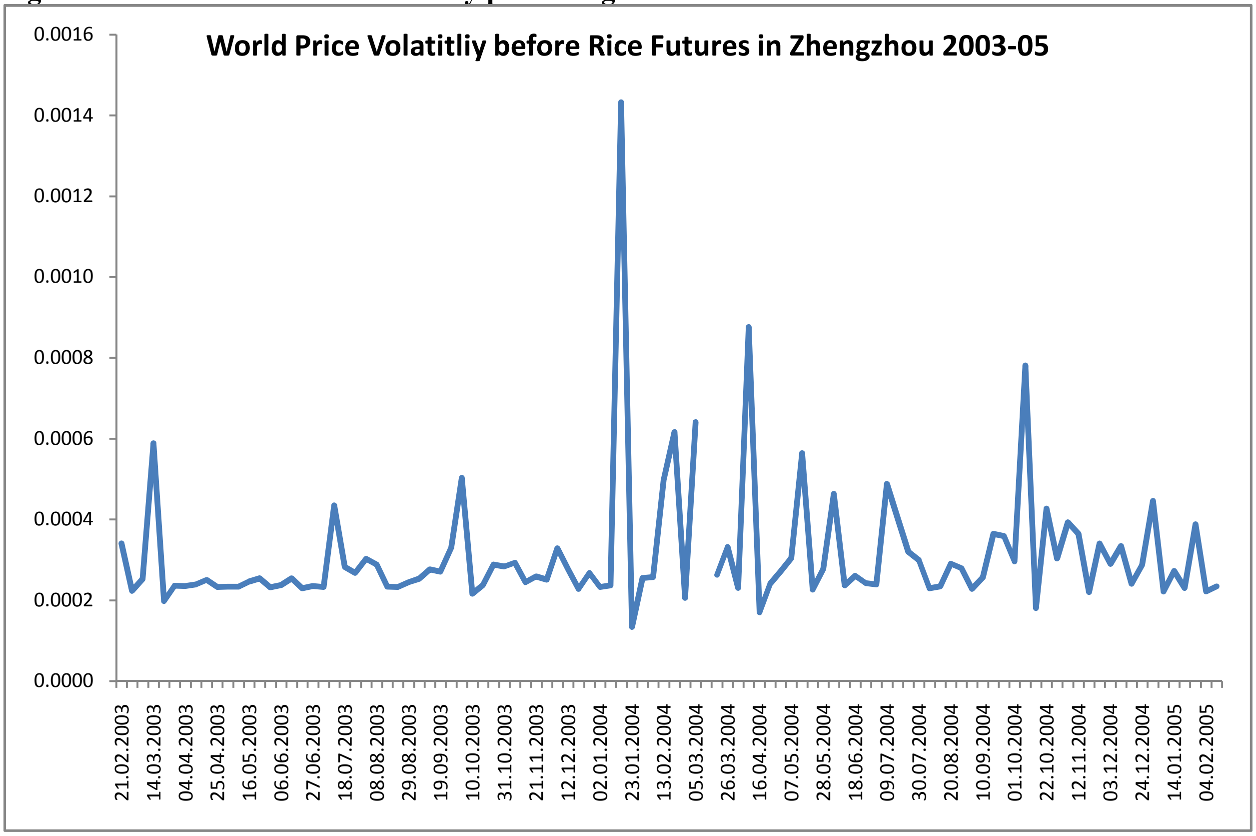


Figure 20: World Rice Price Volatility post Zhengzhou Rice Futures Market

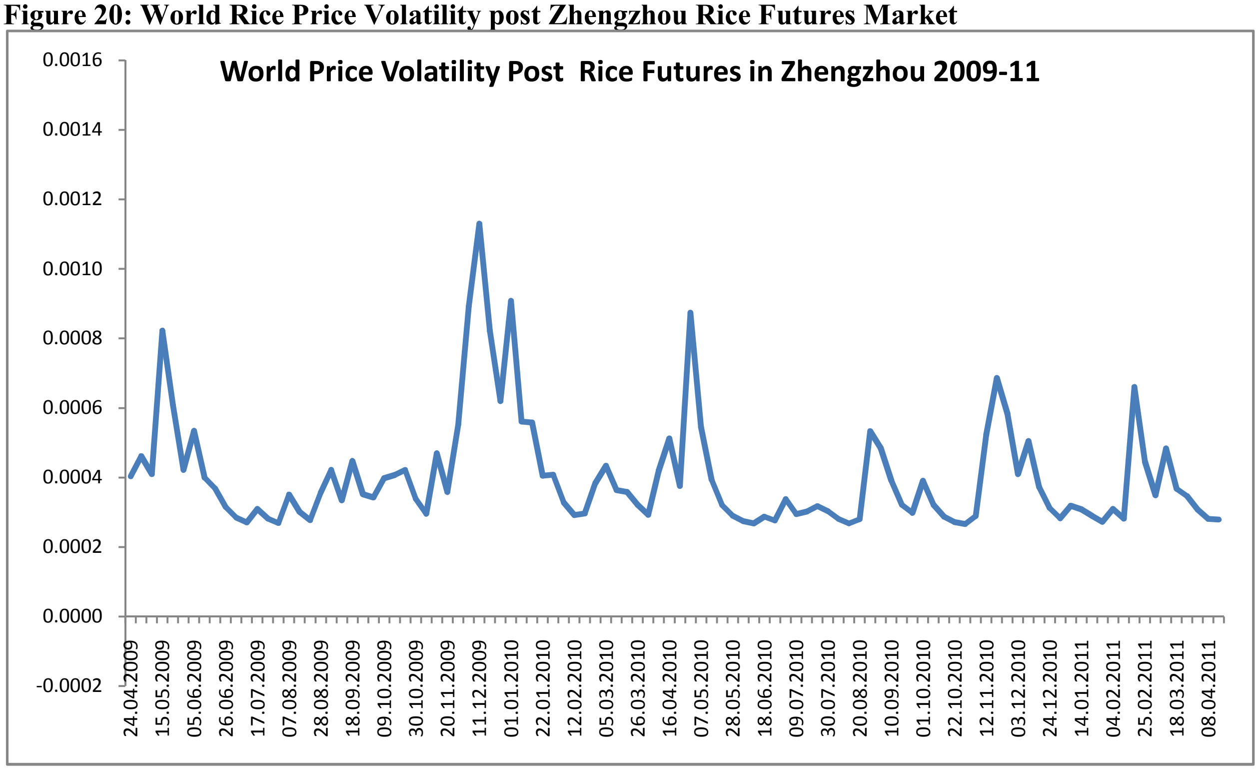


Figure 21: World Price Volatility pre Rice Futures on the CBOT

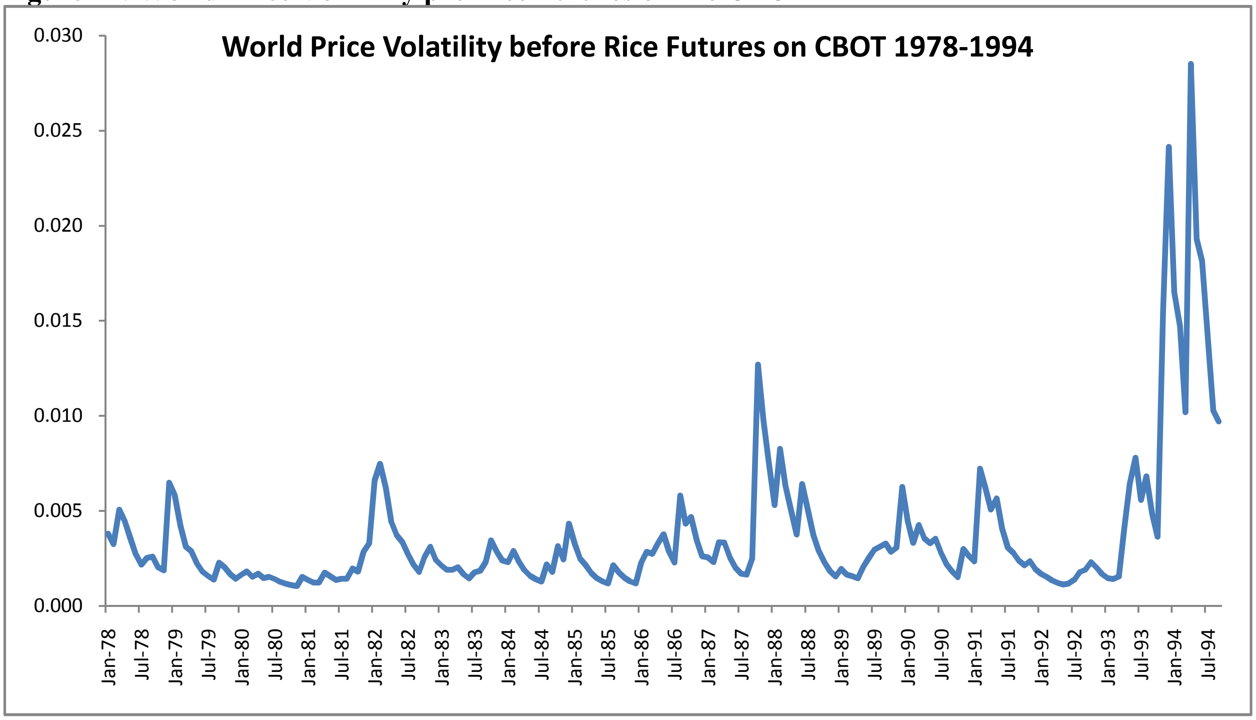
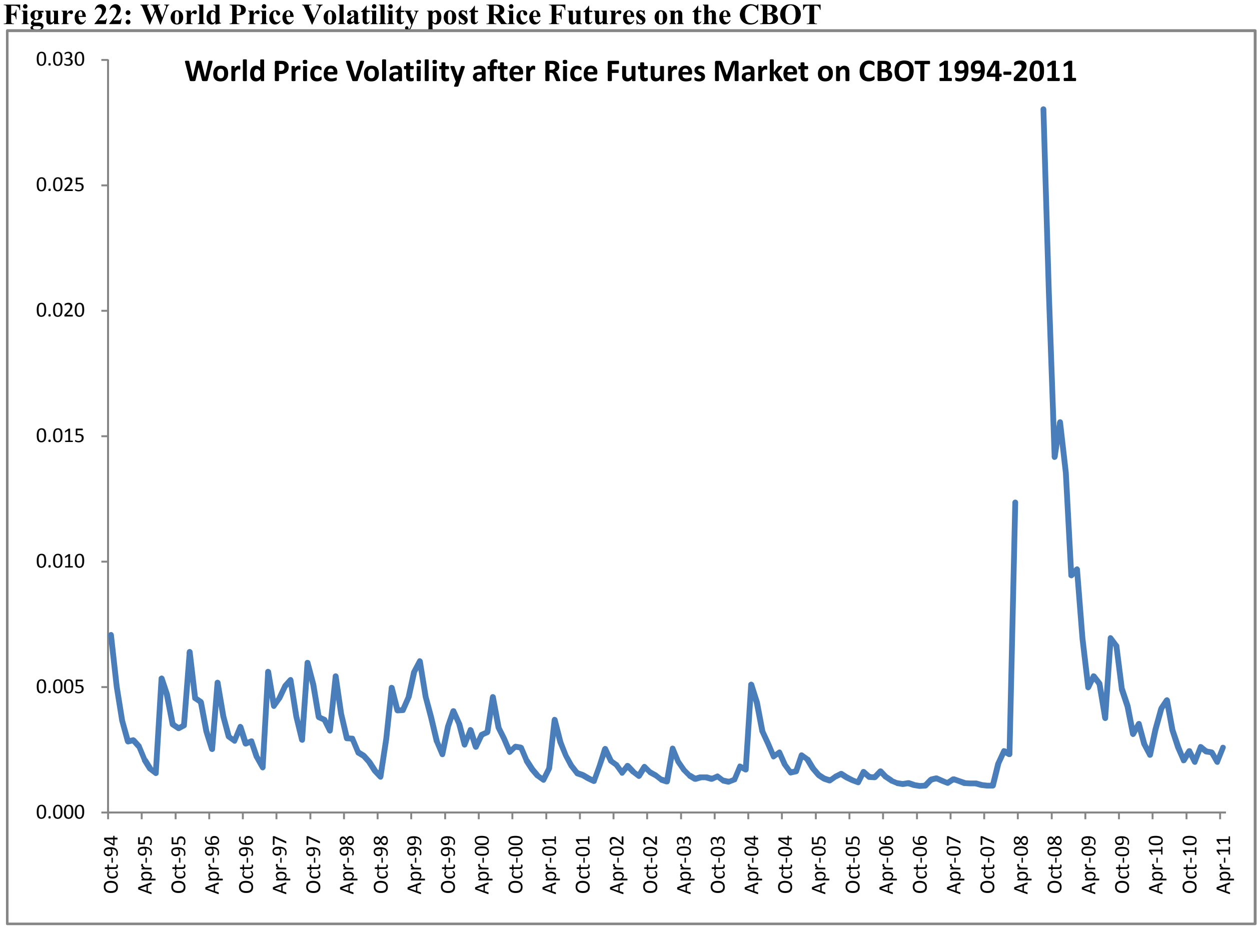


Figure 22: World Price Volatility post Rice Futures on the CBOT



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Appendices

Appendix A: Derivation of Equations 3.7, 3.8 and 3.9

Two periods: t_1 and t_2
State A: $\tilde{\alpha} = \alpha_L$
State B: $\tilde{\alpha} = \alpha_H$
$\tilde{\alpha}$ = t_1 news of Demand in (t_2)
Q_1 = first period endowment
a = intercept value
S = quantity stored in the first period
S^*= equilibrium quantity of storage
m= storage cost
$P_1 = a - Q_1 + S$ = price in t_1 (A.1)
$P_2 = \tilde{\alpha} - S$ = price in t_2 (A.2)
$P_2 - P_1 = m$ (A.3)
Solving for S^*:
$P_2 - P_1 = m$
$\tilde{\alpha} - S - a + Q_1 - S = m$
$S^* = \frac{1}{2}(\tilde{\alpha} + Q_1 - a - m)$ (A.4)

A. Expected Squared Price Difference ($ESPD_{NS}$) (Derivation of 3.7)

$\epsilon = \delta = 0$
$\tilde{\alpha} = \frac{1}{2}\alpha_L + \frac{1}{2}\alpha_H \rightarrow$ equal probability for either high or low demand in second period
$E_{NS}(P_2 - P_1)^2 = \frac{1}{2}[\alpha_L - 2S^* - a + Q_1]^2 + \frac{1}{2}[\alpha_H - 2S^* - a + Q_1]^2$
$= \frac{1}{2}\left[\alpha_L - \left(\frac{1}{2}\alpha_H + \frac{1}{2}\alpha_L + Q_1 - a - m\right) - a + Q_1\right]^2 + \frac{1}{2}\left[\alpha_H - \left(\frac{1}{2}\alpha_H + \frac{1}{2}\alpha_L + Q_1 - a - m\right) - a + Q_1\right]^2$
$= \frac{1}{2}\left[m - \frac{1}{2}(\alpha_H - \alpha_L)\right]^2 + \left[m + \frac{1}{2}(\alpha_H - \alpha_L)\right]^2$
$= \frac{1}{2}m^2 - \frac{1}{2}m(\alpha_H - \alpha_L) + \frac{1}{8}(\alpha_H - \alpha_L)^2 + \frac{1}{2}m^2 + \frac{1}{2}m(\alpha_H - \alpha_L) + \frac{1}{8}(\alpha_H - \alpha_L)^2$
$= m^2 + \frac{1}{4}(\alpha_H - \alpha_L)^2$ = $ESPD_{NS}$ = (T.7) (A.5)
End

B. Expected Squared Price Difference with Speculation ($ESPD_{WS}$) (Derivation of 3.8)

State A: $\tilde{\alpha} = \left(\frac{1}{2} + \epsilon - \delta\right)\alpha_L + \left(\frac{1}{2} - \epsilon + \delta\right)\alpha_H$
State A indicates that t_1 news points to low demand in period 2
State B: $\tilde{\alpha} = \left(\frac{1}{2} - \epsilon - \delta\right)\alpha_L + \left(\frac{1}{2} + \epsilon + \delta\right)\alpha_H$
State B indicates that t_1 news points to high demand in period 2
Equal probability of each state happening

Two possible S^* (please see A. for derivation of S^*):

$$S_A^* = \frac{1}{2}\left[\alpha_L\left(\frac{1}{2} + \epsilon - \delta\right) + \alpha_H\left(\frac{1}{2} - \epsilon + \delta\right) - a + Q_1 - m\right]$$

$$S_B^* = \frac{1}{2}\left[\alpha_L\left(\frac{1}{2} - \epsilon - \delta\right) + \alpha_H\left(\frac{1}{2} + \epsilon + \delta\right) - a + Q_1 - m\right]$$

$$E_{WS}(P_2 - P_1)^2 = \frac{1}{2}\left[\left(\frac{1}{2} + \epsilon\right)\left(P_2^L(A) - P_1(A)\right)^2 + \left(\frac{1}{2} - \epsilon\right)\left(P_2^H(A) - P_1(A)\right)^2\right] + \frac{1}{2}\left[\left(\frac{1}{2} - \epsilon\right)\left(P_2^L(B) - P_1(B)\right)^2 + \left(\frac{1}{2} + \epsilon\right)\left(P_2^H(B) - P_1(B)\right)^2\right] \quad \text{(A.6)}$$

Begin Aside:

Recall $P_2 - P_1 = \tilde{\alpha} - 2S^* + m$

Therefore:

$$\left(P_2^L(A) - P_1(A)\right)^2 = (\alpha_L - [\tilde{\alpha} - (\epsilon - \delta)(\alpha_H - \alpha_L) + m])^2 \quad \text{(A.7)}$$

$$\left(P_2^H(A) - P_1(A)\right)^2 = (\alpha_H - [\tilde{\alpha} - (\epsilon - \delta)(\alpha_H - \alpha_L) + m])^2 \quad \text{(A.8)}$$

$$\left(P_2^L(B) - P_1(B)\right)^2 = (\alpha_L - [\tilde{\alpha} + (\epsilon + \delta)(\alpha_H - \alpha_L) + m])^2 \quad \text{(A.9)}$$

$$\left(P_2^H(A) - P_1(A)\right)^2 = (\alpha_H - [\tilde{\alpha} + (\epsilon + \delta)(\alpha_H - \alpha_L) + m])^2 \quad \text{(A.10)}$$

Rearrange (A.7):

(I.7) $= \quad (\alpha_L - [\tilde{\alpha} - \epsilon\alpha_H + \epsilon\alpha_L + \delta\alpha_H - \delta\alpha_L + m])^2 = \left(\alpha_L - \frac{1}{2}\alpha_L - \frac{1}{2}\alpha_H + \epsilon\alpha_H - \epsilon\alpha_L - \delta\alpha_H + \delta\alpha_L - m\right)^2 =$
$\left(\frac{1}{2}\alpha_L - \frac{1}{2}\alpha_H + \epsilon\alpha_H - \epsilon\alpha_L - \delta\alpha_H + \delta\alpha_L - m\right)^2 = \left(\epsilon(\alpha_H - \alpha_L) - \delta(\alpha_H - \alpha_L) - \frac{1}{2}(\alpha_H - \alpha_L) - m\right)^2$
$= \left[\left(\epsilon - \delta - \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]^2 = \left[\left(\epsilon - \delta - \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]\left[\left(\epsilon - \delta - \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]$
$= (Z - m)(Z - m) = (Z - m)^2$

Rearrange (A.8):

(I.8) $= \left(\epsilon(\alpha_H - \alpha_L) - \delta(\alpha_H - \alpha_L) + \frac{1}{2}(\alpha_H - \alpha_L) - m\right)^2$
$= \left[\left(\epsilon - \delta + \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]^2 = (Y - m)^2$

Rearrange (A.9):

(I.9) $= \left(-\epsilon(\alpha_H - \alpha_L) - \delta(\alpha_H - \alpha_L) - \frac{1}{2}(\alpha_H - \alpha_L) - m\right)^2$
$\left[\left(-\epsilon - \delta - \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]^2 = (W - m)^2$

Rearrange (A.10):

(I.10) $= \left(-\epsilon(\alpha_H - \alpha_L) - \delta(\alpha_H - \alpha_L) + \frac{1}{2}(\alpha_H - \alpha_L) - m\right)^2$
$= \left[\left(-\epsilon - \delta + \frac{1}{2}\right)(\alpha_H - \alpha_L) - m\right]^2 = (F - m)^2$

End Aside

(A.6) $= \frac{1}{2}\left[\left(\frac{1}{2} + \epsilon\right)(Z - m)^2 + \left(\frac{1}{2} - \epsilon\right)(Y - m)^2\right] + \frac{1}{2}\left[\left(\frac{1}{2} - \epsilon\right)(W - m)^2 + \left(\frac{1}{2} + \epsilon\right)(F - m)^2\right]$
$= \frac{1}{2}\left[\left(\frac{1}{2} + \epsilon\right)(Z - m)^2 + \left(\frac{1}{2} - \epsilon\right)(Y - m)^2 + \left(\frac{1}{2} - \epsilon\right)(W - m)^2 + \left(\frac{1}{2} + \epsilon\right)(F - m)^2\right]$
$= \frac{1}{2}\left[2m^2 - m(Z + Y + W + F) + \epsilon(Z^2 - Y^2 - W^2 + F^2) + \frac{1}{2}(Z^2 + Y^2 + W^2 + F^2) - 2\epsilon m(Z - Y - W + F)\right]$
(A.11)

Aside

$(\boldsymbol{Z}+\boldsymbol{Y}+\boldsymbol{W}+\boldsymbol{F})$

$$\begin{aligned}&=\left(\epsilon-\delta-\frac{1}{2}\right)(\alpha_H-\alpha_L)+\left(\epsilon-\delta+\frac{1}{2}\right)(\alpha_H-\alpha_L)+\left(-\epsilon-\delta-\frac{1}{2}\right)(\alpha_H-\alpha_L)\\&+\left(-\epsilon-\delta+\frac{1}{2}\right)(\alpha_H-\alpha_L)\\&=(\alpha_H-\alpha_L)\left[\epsilon-\delta-\frac{1}{2}+\epsilon-\delta+\frac{1}{2}-\epsilon-\delta-\frac{1}{2}+\frac{1}{2}-\epsilon-\delta\right]\\&=-4\delta(\alpha_H-\alpha_L)\end{aligned} \tag{A.12}$$

$(\boldsymbol{Z}^2-\boldsymbol{Y}^2-\boldsymbol{W}^2+\boldsymbol{F}^2)$

$$\begin{aligned}&=\left(\epsilon-\delta-\frac{1}{2}\right)^2(\alpha_H-\alpha_L)^2-\left(\epsilon-\delta+\frac{1}{2}\right)^2(\alpha_H-\alpha_L)^2\\&-\left(-\epsilon-\delta-\frac{1}{2}\right)^2(\alpha_H-\alpha_L)^2+\left(-\epsilon-\delta+\frac{1}{2}\right)^2(\alpha_H-\alpha_L)^2\\&=(\alpha_H-\alpha_L)^2\left[\epsilon^2-2\epsilon\delta-\epsilon+\delta^2+\delta+\frac{1}{4}-\epsilon^2+2\epsilon\delta-\epsilon-\delta^2+\delta-\frac{1}{4}-\epsilon^2\right.\\&\left.-2\epsilon\delta-\epsilon-\delta^2-\delta-\frac{1}{4}+\frac{1}{4}-\epsilon-\delta+\epsilon^2+2\epsilon\delta+\delta^2\right]=-4\epsilon(\alpha_H-\alpha_L)^2\end{aligned} \tag{A.13}$$

$(\boldsymbol{Z}^2+\boldsymbol{Y}^2+\boldsymbol{W}^2+\boldsymbol{F}^2)$

$$\begin{aligned}&=(\alpha_H-\alpha_L)^2\left[\epsilon^2-2\epsilon\delta-\epsilon+\delta^2+\delta+\frac{1}{4}+\epsilon^2-2\epsilon\delta+\epsilon-+\frac{1}{4}+\epsilon^2+2\epsilon\delta\right.\\&\left.+\epsilon+\delta^2+\delta+\frac{1}{4}+\frac{1}{4}-\epsilon-\delta+\epsilon^2+2\epsilon\delta+\delta^2\right]=(4\epsilon^2+4\delta^2+1)(\alpha_H-\alpha_L)^2\end{aligned} \tag{A.14}$$

$$(\boldsymbol{Z}-\boldsymbol{Y}-\boldsymbol{W}+\boldsymbol{F})=(\alpha_H-\alpha_L)\left[\epsilon-\delta-\tfrac{1}{2}-\epsilon+\delta-\tfrac{1}{2}+\epsilon+\delta+\tfrac{1}{2}+\tfrac{1}{2}-\epsilon-\delta\right]=0 \tag{A.15}$$

End Aside

Going back to (A.6) deriving (3.8):

$E_{WS}(P_2-P_1)^2$

$$\begin{aligned}&=\frac{1}{2}\Big[2m^2-m\big(-4\delta(\alpha_H-\alpha_L)\big)+\epsilon(-4\epsilon(\alpha_H-\alpha_L)^2)\\&+\frac{1}{2}(4\epsilon^2+4\delta^2+1)(\alpha_H-\alpha_L)^2-2\epsilon m(0)\Big]\\&=\frac{1}{2}\left[2m^2+4m\delta(\alpha_H-\alpha_L)-(\alpha_H-\alpha_L)^2\left(2\epsilon^2-2\delta^2-\frac{1}{2}\right)\right]\\&=m^2+2m\delta(\alpha_H-\alpha_L)-\epsilon^2(\alpha_H-\alpha_L)^2+\delta^2(\alpha_H-\alpha_L)^2+\frac{1}{4}(\alpha_H-\alpha_L)^2\\&=(3.8)\end{aligned} \tag{A.16}$$

(A.16) is the $ESPD_{WS}$. As the value of ϵ increases, $ESPD_{WS}$ falls. As the value of δ increases, $ESPD_{WS}$ rises.

Value of δ* Derivation of 3.9

In order to derive the value of δ^*, (3.7) has to be set equal to (3.8)

$ESPD_{NS} = ESPD_{WS} \rightarrow$

$m^2 + \frac{1}{4}(\alpha_H - \alpha_L)^2 = m^2 + 2m\delta(\alpha_H - \alpha_L) - \epsilon^2(\alpha_H - \alpha_L)^2 + \delta^2(\alpha_H - \alpha_L)^2 + \frac{1}{4}(\alpha_H - \alpha_L)^2$

$2m\delta(\alpha_H - \alpha_L) - \epsilon^2(\alpha_H - \alpha_L)^2 + \delta^2(\alpha_H - \alpha_L)^2 = 0$

Use quadratic formula to solve for δ:

$$\delta = \frac{-2m(\alpha_H - \alpha_L) \pm \sqrt{\left(2m(\alpha_H - \alpha_L)\right)^2 - 4(\alpha_H - \alpha_L)^2(-\epsilon^2(\alpha_H - \alpha_L)^2)}}{2(\alpha_H - \alpha_L)^2}$$

$$= \frac{-2m(\alpha_H - \alpha_L) \pm \sqrt{4m^2(\alpha_H - \alpha_L) + 4(\alpha_H - \alpha_L)^2(\epsilon^2(\alpha_H - \alpha_L)^2)}}{2(\alpha_H - \alpha_L)^2}$$

$$= \frac{-2m(\alpha_H - \alpha_L) \pm 2(\alpha_H - \alpha_L)\sqrt{m^2 + \epsilon^2(\alpha_H - \alpha_L)^2}}{2(\alpha_H - \alpha_L)^2}$$

$$= \frac{-m \pm \sqrt{m^2 + \epsilon^2(\alpha_H - \alpha_L)^2}}{(\alpha_H - \alpha_L)}$$

$\delta = \frac{-m - \sqrt{m^2 + \epsilon^2(\alpha_H - \alpha_L)^2}}{(\alpha_H - \alpha_L)} = negative\ value$

$\delta^* = \frac{-m + \sqrt{m^2 + \epsilon^2(\alpha_H - \alpha_L)^2}}{(\alpha_H - \alpha_L)}$ = (3.9)

Appendix B: Another GARCH Model

The GARCH-in-mean (GARCH-M) model is one of those which may allow for a better estimation of the rice spot returns. The general equation for the GARCH-M model is:

$$y_t = \alpha + \sum_{i=1}^{q} \beta_i y_{t-i} + \delta h_t + \epsilon_t \qquad \text{(B.1)}$$

GARCH-M allows the conditional variance to provide an explanation for the dependent variable, and equation (4.4) becomes:

$$r_t = \beta_o + \beta_1 CRB_t + \beta_2 WP_t + \delta h_t + \epsilon_t \qquad \text{(B.2)}$$

Where h_t is defined by equation (4.3).

The GARCH-M model is a general form of the GARCH model which adds the current period conditional variance (h_t) as an exogenous variable to the model estimating the current period returns (r_t). GARCH-M has a few advantages over the conventional GARCH model. The GARCH-M model allows for the spot price return to be expressed directly as a function of conditional variance. Two other characteristics which are thought to be appealing to the rice market are discussed here. First, excluding the error variance (h_t) from equation (B.2) when price fluctuation is high during the sample period, may ignore the problems of heteroskedasticity. Second, GARCH-M model explains how much of the return is due to the current period volatility (Brewer, Carson, Elyasiani, Mansur, & Scott, 2007).

Appendix C: Another Form of Equation (4.7)

This section presents another form of equation (4.7), which controls for the past values of the dummy variable while determining the current period's volatility.

For simplicity P_t from equation (4.7) is ignored and that equation is takes the following form.

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t \quad \text{(C.1)}$$

In order to remove the effect of last period's dummy on current period's volatility (J.1) has to take the following form:

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(h_{t-1} - \alpha_3 D_{t-1}) + \alpha_3 D_t \quad \text{(C.2)}$$

$$\begin{aligned} h_t &= \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(h_{t-1} - \alpha_3 D_{t-1}) + \alpha_3 D_t \\ &= \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2([\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(h_{t-2} - \alpha_3 D_{t-2}) + \alpha_3 D_{t-1}] - \alpha_3 D_{t-1}) + \alpha_3 D_t \\ &= \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(h_{t-2} - \alpha_3 D_{t-2}) + \alpha_3 D_t \\ &= \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-3}^2 + \alpha_2(h_{t-3} - \alpha_3 D_{t-3}) + \alpha_3 D_{t-2}) - \alpha_3 D_{t-2}) \\ &\quad + \alpha_3 D_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-3}^2 + \alpha_2(h_{t-3} - \alpha_3 D_{t-3}))) + \alpha_3 D_t \end{aligned}$$

Repeating this process to infinity:

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-3}^2 + \alpha_2(\alpha_o + \alpha_1 \epsilon_{t-4}^2 + \ldots\ldots + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-\infty}^2 + \alpha_2(h_{t-\infty} - \alpha_3 D_{t-\infty})))) + \alpha_3 D_t \quad \text{(C.3)}$$

Expanding (C.3)

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2\alpha_\circ + \alpha_2\alpha_1 \epsilon_{t-2}^2 + \alpha_2^2\alpha_\circ + \alpha_2^2\alpha_1 \epsilon_{t-3}^2 + \alpha_2^3\alpha_o + \alpha_2^3\alpha_1 \epsilon_{t-4}^2 + \cdots + \alpha_2^{\infty-1}\alpha_o + \alpha_2^{\infty-1}\epsilon_{t-\infty}^2 + \alpha_2^{\infty-1}(h_{t-\infty} - \alpha_3 D_{t-\infty}) + \alpha_3 D_t \quad \text{(C.4)}$$

$\alpha_2 < 1$ because volatility from periods further in the past contributes less to the volatility in the current period. Therefore,

$$\alpha_2^{\infty-1} \approx 0 \quad \text{(C.5)}$$

and (C.4) becomes:

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2\alpha_\circ + \alpha_2\alpha_1 \epsilon_{t-2}^2 + \alpha_2^2\alpha_\circ + \alpha_2^2\alpha_1 \epsilon_{t-3}^2 + \alpha_2^3\alpha_o + \alpha_2^3\alpha_1 \epsilon_{t-4}^2 + \cdots + \alpha_2^{\infty-1}\alpha_o + \alpha_2^{\infty-1}\epsilon_{t-\infty}^2 + D_t \quad \text{(C.6)}$$

Therefore, the only dummy value that is left is D_t. The dummy variable in each period explains the volatility h_t in that period and not the volatility in future periods. Not subtracting previous period dummy variable values yields the following result.

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \alpha_2(h_{t-2}) + \alpha_3 D_{t-1}) + \alpha_3 D_t \quad \text{(C.7)}$$

Repeating this process to infinity, it becomes evident that dummy variables from all previous periods are explanatory variables for the current volatility h_t. Therefore, (C.7) becomes:

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-2}^2 + \cdots + \alpha_2(\alpha_\circ + \alpha_1 \epsilon_{t-\infty}^2 + \alpha_2 h_{t-\infty} + \alpha_3 D_{t-\infty+1}) + \cdots + \alpha_3 D_{t-1}) + \alpha_3 D_t \quad \text{(C.8)}$$

Appendix D: Seasonality Test Results (Stata Output)

Wheat Seasonality Test

```
. tabulate month, gen(m)

      month |      Freq.     Percent        Cum.
------------+-----------------------------------
        Apr |         23        8.13        8.13
        Aug |         24        8.48       16.61
        Dec |         24        8.48       25.09
        Feb |         23        8.13       33.22
        Jan |         24        8.48       41.70
        Jul |         24        8.48       50.18
        Jun |         23        8.13       58.30
        Mar |         23        8.13       66.43
        May |         23        8.13       74.56
        Nov |         24        8.48       83.04
        Oct |         24        8.48       91.52
        Sep |         24        8.48      100.00
------------+-----------------------------------
      Total |        283      100.00

. reg rtrnw m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 m12, noconstant

      Source |       SS       df       MS              Number of obs =     283
-------------+------------------------------           F( 12,   271) =    3.87
       Model |  .104940799    12  .008745067           Prob > F      =  0.0000
    Residual |  .612487282   271  .002260101           R-squared     =  0.1463
-------------+------------------------------           Adj R-squared =  0.1085
       Total |  .717428081   283  .002535082           Root MSE      =  .04754

------------------------------------------------------------------------------
       rtrnw |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          m1 |  -.0022488   .0099129    -0.23   0.821    -.0217648    .0172673
          m2 |   .0165187   .0097042     1.70   0.090    -.0025865    .0356238
          m3 |   .0101389   .0097042     1.04   0.297    -.0089662    .0292441
          m4 |  -.0039844   .0099129    -0.40   0.688    -.0235005    .0155316
          m5 |   .0005898   .0097042     0.06   0.952    -.0185153    .0196949
          m6 |  -.0310489   .0097042    -3.20   0.002     -.050154   -.0119437
          m7 |  -.0397279   .0099129    -4.01   0.000     -.059244   -.0202119
          m8 |   .0000231   .0099129     0.00   0.998    -.0194929    .0195392
          m9 |  -.0112847   .0099129    -1.14   0.256    -.0308007    .0082314
         m10 |   .0086941   .0097042     0.90   0.371    -.0104111    .0277992
         m11 |   .0284294   .0097042     2.93   0.004     .0093243    .0475346
         m12 |   .0222267   .0097042     2.29   0.023     .0031215    .0413318
------------------------------------------------------------------------------
```

Rice Seasonality Test

```
. tabulate month, gen(m)

      month |      Freq.     Percent        Cum.
------------+-----------------------------------
        Apr |         28        8.19        8.19
        Aug |         28        8.19       16.37
        Dec |         29        8.48       24.85
        Feb |         29        8.48       33.33
        Jan |         29        8.48       41.81
        Jul |         28        8.19       50.00
        Jun |         28        8.19       58.19
        Mar |         28        8.19       66.37
        May |         28        8.19       74.56
        Nov |         29        8.48       83.04
      month |         Freq.     Percent     Cum.
        Oct |         29        8.48       91.52
        Sep |         29        8.48      100.00
------------+-----------------------------------
```

```
      Total |        342      100.00

. reg spot m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 m12, noconstant

      Source |       SS       df       MS              Number of obs =     342
-------------+------------------------------           F( 12,   330) =    1.72
       Model |  .063835781    12  .005319648           Prob > F      =  0.0616
    Residual |  1.02154456   330   .00309559           R-squared     =  0.0588
-------------+------------------------------           Adj R-squared =  0.0246
       Total |  1.08538034   342  .003173627           Root MSE      =  .05564

------------------------------------------------------------------------------
        spot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          m1 |  -.0102574   .0105146    -0.98   0.330    -.0309415    .0104267
          m2 |   -.001397   .0105146    -0.13   0.894    -.0220811    .0192871
          m3 |   .0108695   .0103317     1.05   0.294    -.0094548    .0311939
          m4 |   .0025304   .0103317     0.24   0.807    -.0177939    .0228548
          m5 |   .0095848   .0103317     0.93   0.354    -.0107396    .0299091
          m6 |  -.0101483   .0105146    -0.97   0.335    -.0308324    .0105358
          m7 |  -.0089429   .0105146    -0.85   0.396     -.029627    .0117412
          m8 |  -.0072255   .0105146    -0.69   0.492    -.0279096    .0134586
          m9 |  -.0144594   .0105146    -1.38   0.170    -.0351435    .0062247
         m10 |   .0308802   .0103317     2.99   0.003     .0105559    .0512046
         m11 |   .0221058   .0103317     2.14   0.033     .0017814    .0424301
         m12 |   -.003188   .0103317    -0.31   0.758    -.0235124    .0171363
------------------------------------------------------------------------------
```

Rice Futures Price Seasonality Test (Stata output)

```
. tabulate month, gen(m)

      month |      Freq.     Percent        Cum.
------------+-----------------------------------
        Apr |         12        8.96        8.96
        Aug |         11        8.21       17.16
        Dec |         11        8.21       25.37
        Feb |         11        8.21       33.58
        Jan |         11        8.21       41.79
        Jul |         11        8.21       50.00
        Jun |         11        8.21       58.21
        Mar |         12        8.96       67.16
        May |         11        8.21       75.37
        Nov |         11        8.21       83.58
        Oct |         11        8.21       91.79
        Sep |         11        8.21      100.00
------------+-----------------------------------
      Total |        134      100.00

. reg futspot m1 m2 m3 m4 m5 m6 m7 m8 m9 m10 m11 m12, noconstant

      Source |       SS       df       MS              Number of obs =     134
-------------+------------------------------           F( 12,   122) =    0.89
       Model |  .077935625    12  .006494635           Prob > F      =  0.5588
    Residual |  .890072269   122  .007295674           R-squared     =  0.0805
-------------+------------------------------           Adj R-squared = -0.0099
       Total |  .968007894   134   .00722394           Root MSE      =  .08541

------------------------------------------------------------------------------
     futspot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
          m1 |  -.0081064   .0246571    -0.33   0.743    -.0569176    .0407048
          m2 |  -.0000467   .0257535    -0.00   0.999    -.0510283    .0509349
          m3 |   .0119898   .0257535     0.47   0.642    -.0389919    .0629714
     futspot |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]

          m4 |  -.0057409   .0257535    -0.22   0.824    -.0567225    .0452408
          m5 |  -.0024888   .0257535    -0.10   0.923    -.0534704    .0484928
          m6 |  -.0406545   .0257535    -1.58   0.117    -.0916361    .0103272
          m7 |   -.011686   .0257535    -0.45   0.651    -.0626677    .0392956
          m8 |   .0474054   .0246571     1.92   0.057    -.0014058    .0962167
```

futspot	Coef.	Std. Err.	t	P>|t|	[95% Conf.	Interval]
m9	.0463902	.0257535	1.80	0.074	-.0045915	.0973718
m10	.0168421	.0257535	0.65	0.514	-.0341396	.0678237
m11	.0108874	.0257535	0.42	0.673	-.0400943	.061869
m12	-.0059414	.0257535	-0.23	0.818	-.056923	.0450403

Appendix E: Different Ordering of Variables in I.R. and FEVD Analysis

Different ordering of variables in a VAR model could yield different results. However, as indicated in section 4.2.1, different ordering of variables do not change the results of this study, because there are only two explanatory variables (trading volume and open interest) other than dependent variable (price volatility). Therefore the following two VAR models, where the position of trading volume (TV) and open interest (OI) have been changed in the second model are tested and the results compared. The CMA method is used to detrend the futures trading volume and open interest. The first VAR model, used in this study and indicated by equations (4.12-4.14) in section 4.2, is represented by the following set of equations here:

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \varepsilon_t \qquad \text{(E.1)}$$

$$TV_t = b_o + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + u_t \qquad \text{(E.2)}$$

$$OI_t = c_o + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + \tau TV_t + v_t \qquad \text{(E.3)}$$

The second VAR model with changing of the order of the explanatory variables (TV and OI) is represented by the following set of equations:

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i OI_{t-i} + \sum_{i=1}^{r} \gamma_i TV_{t-i} + \varepsilon_t \qquad \text{(E.4)}$$

$$OI_t = b_o + \sum_{i=1}^{q} \beta_i OI_{t-i} + \sum_{i=1}^{r} \gamma_i TV_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + u_t \qquad \text{(E.5)}$$

$$TV_t = c_o + \sum_{i=1}^{r} \gamma_i TV_{t-i} + \sum_{i=1}^{q} \beta_i OI_{t-i} + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \varphi \sigma_t + \tau OI_t + v_t \qquad \text{(E.6)}$$

The results of the Granger Causality Test, IR, and FEVD analyses are reported in the following tables (Stata outputs). There is clear indication that different ordering of variables in the VAR did not alter the results of this study. The VAR model that is used in this study (equations E.1 to E.3) is referred to as Model 1 and the one represented by equations E.4 to E.6 is referred to as Model 2.

Granger Causality Test

Model 1

```
   Granger causality Wald tests
```

Equation	Excluded	chi2	df	Prob > chi2
garchm	cmavol	13.418	3	0.004
garchm	cmaoi	3.6074	3	0.307
garchm	ALL	17.423	6	0.008
cmavol	garchm	2.4016	3	0.493
cmavol	cmaoi	21.101	3	0.000
cmavol	ALL	25.187	6	0.000
cmaoi	garchm	12.257	3	0.007
cmaoi	cmavol	.54747	3	0.908
cmaoi	ALL	13.089	6	0.042

Model 2

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
garchm	cmaoi	3.6074	3	0.307
garchm	cmavol	13.418	3	0.004
garchm	ALL	17.423	6	0.008
cmaoi	garchm	12.257	3	0.007
cmaoi	cmavol	.54747	3	0.908
cmaoi	ALL	13.089	6	0.042
cmavol	garchm	2.4016	3	0.493
cmavol	cmaoi	21.101	3	0.000
cmavol	ALL	25.187	6	0.000

Impulse Response Analysis (IR)

Model 1:

Step	garch-garch	TV-garch	OI-garch
1	0.655796	-0.00477	0.008841
2	0.267846	-0.00663	0.004279
3	0.09384	-0.00272	-0.00086
4	0.06486	0.002445	-0.00469
5	0.064405	0.000698	-0.00231
6	0.070075	-0.00159	0.001726
7	0.042706	-0.00149	0.003159
8	0.001602	0.000463	-0.00044
9	-0.01762	0.000623	-0.00225
10	0.004971	1.90E-06	-0.00066

Model 2:

Step	garch-garch	OI-garch	TV-garch
1	0.655796	0.008841	-0.00477
2	0.267846	0.004279	-0.00663
3	0.09384	-0.00086	-0.00272
4	0.06486	-0.00469	0.002445
5	0.064405	-0.00231	0.000698
6	0.070075	0.001726	-0.00159
7	0.042706	0.003159	-0.00149
8	0.001602	-0.00044	0.000463
9	-0.01762	-0.00225	0.000623
10	0.004971	-0.00066	1.90E-06

Note:

- garch-garch indicates the impact of a shock in the current volatility of cash price on future volatility of the cash price of rice (garch)
- TV-garch indicates the impact of a shock in detrended futures trading volume (TV) on future volatility of the cash price of rice (garch)

- OI-garch indicates the impact of a shock in detrended futures open interest (OI) on future volatility of the cash price of rice (garch)
- Ten steps are chosen as beyond 10^{th} period the effect of the shocks become very small in magnitude

Forecast Error Variance Decomposition (FEVD)

Model 1 Model 2

Step	garch-garch	TV-garch	OI-garch	Step	garch-garch	OI-garch	TV-garch
1	1	0	0	1	1	0	0
2	0.953134	0.017641	0.029225	2	0.953134	0.02848	0.018386
3	0.902067	0.019605	0.078327	3	0.902067	0.077195	0.020737
4	0.894453	0.019573	0.085975	4	0.894453	0.084897	0.020651
5	0.884734	0.023701	0.091564	5	0.884734	0.090321	0.024944
98	0.874527	0.028739	0.096735	98	0.874527	0.095336	0.030137
99	0.874527	0.028739	0.096735	99	0.874527	0.095336	0.030137
100	0.874527	0.028739	0.096735	100	0.874527	0.095336	0.030137

Note:
- garch-garch indicates the impact of a shock in the current volatility of cash price on future unpredictability (error) in estimating future volatility of the cash price of rice (garch)
- TV-garch indicates the impact of a shock in detrended futures trading volume (TV) on future unpredictability (error) in estimating future volatility of the cash price of rice (garch)
- OI-garch indicates the impact of a shock in detrended futures open interest (OI) on unpredictability (error) in estimating future volatility of the cash price of rice (garch)
- 100 steps are chosen to have long enough horizon and assess the long term impact of current shocks to TV and OI on cash price volatility

Appendix F: Choosing Separate Lags for each Variable of a VAR Model

Choosing all lags for all variables to be equal could lead to rapid loss of degrees of freedom in the model. Granger causality test is sensitive to the selection of lag orders. Including insignificant lags could lead to rejecting the null hypothesis of the Granger causality test where one should fail to reject it. Atukeren (2005) suggests a few steps to identify the appropriate lag orders and these steps are adopted in this work. First, the following autoregressions are estimated based on lag orders p=1 to 8. The autoregression with the lowest AIC value identifies the appropriate value of p.

$$\sigma_t = a_o + \sum_{i=1}^{p} \varphi_i \sigma_{t-i} + v_t \tag{F.1}$$

Second, lagged values of TV are added to equation (F.1), and several autoregressions based lag orders q = 1 to 8 are estimated. The estimation with the lowest AIC identifies the appropriate value for q and of course p was determined in the first step.

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + u_t \tag{F.2}$$

Same process is continued in step three to find the appropriate lag order for OI (r value).

$$\sigma_t = a_o + \sum_{i=1}^{p} \alpha_i \sigma_{t-i} + \sum_{i=1}^{q} \beta_i TV_{t-i} + \sum_{i=1}^{r} \gamma_i OI_{t-i} + \varepsilon_t \tag{F.3}$$

OI and TV are detrended values of futures contract trading volume and open interest

After each stage if the AIC from estimating the bivariate (equation F.2) or the trivariate (equation F.3) models is lower than that obtained from estimating the autoregression in (F.1), then that is an indication that TV (alone) and TV and OI Granger cause σ (Atukeren, 2005). However, this work uses Granger's original method of choosing all variable lengths the same. There are only three variables in the current VAR model, and given the low frequency of the data, it is believed that the lag lengths are fairly close to one another.

Appendix G: Monthly Variance Generated by GARCH (1,1) Model

Rough Rice

Before the Introduction of Rice Futures Contracts on the CBOT

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Sep-82	0.0035257	Oct-85	0.0012828	Dec-88	0.0021625	Jan-92	0.000996
Oct-82	0.0034043	Nov-85	0.0010716	Jan-89	0.0021096	Feb-92	0.0008484
Nov-82	0.0020686	Dec-85	0.0009073	Feb-89	0.002052	Mar-92	0.0007816
Dec-82	0.0012752	Jan-86	0.0009489	Mar-89	0.0020352	Apr-92	0.000912
Jan-83	0.001083	Feb-86	0.0007734	Apr-89	0.0019288	May-92	0.0014334
Feb-83	0.0007312	Mar-86	0.0007493	May-89	0.0018112	Jun-92	0.0016538
Mar-83	0.0006734	Apr-86	0.0041169	Jun-89	0.001542	Jul-92	0.0016014
Apr-83	0.0009526	May-86	0.0381241	Jul-89	0.0013556	Aug-92	0.0017977
May-83	0.0008804	Jun-86	0.0395468	Aug-89	0.001553	Sep-92	0.0026311
Jun-83	0.0007085	Jul-86	0.0401789	Sep-89	0.0011611	Oct-92	0.0026041
Jul-83	0.0008541	Aug-86	0.0348185	Oct-89	0.00128	Nov-92	0.0025331
Aug-83	0.0006628	Sep-86	0.0349172	Nov-89	0.0012968	Dec-92	0.0025127
Sep-83	0.000912	Oct-86	0.0352923	Dec-89	0.0013947	Jan-93	0.0025482
Oct-83	0.0005857	Nov-86	0.0341708	Jan-90	0.0011198	Feb-93	0.0030201
Nov-83	0.0008894	Dec-86	0.0365883	Feb-90	0.0015763	Mar-93	0.0045487
Dec-83	0.0005787	Jan-87	0.0421163	Mar-90	0.0011661	Apr-93	0.0059408
Jan-84	0.0004301	Feb-87	0.0395152	Apr-90	0.001025	May-93	0.0070729
Feb-84	0.0003172	Mar-87	0.0426977	May-90	0.0010139	Jun-93	0.0087642
Mar-84	0.0006228	Apr-87	0.0443778	Jun-90	0.0010496	Jul-93	0.0106368
Apr-84	0.0006022	May-87	0.0423127	Jul-90	0.0011577	Aug-93	0.0104125
May-84	0.0005588	Jun-87	0.0433015	Aug-90	0.0015778	Sep-93	0.0102445
Jun-84	0.0006348	Jul-87	0.0469157	Sep-90	0.0030803	Oct-93	0.0070498
Jul-84	0.0005183	Aug-87	0.0416929	Oct-90	0.0044404	Nov-93	0.0063384
Aug-84	0.0005017	Sep-87	0.0328997	Nov-90	0.0041711	Dec-93	0.0155953
Sep-84	0.00046	Oct-87	0.0197929	Dec-90	0.0044109	Jan-94	0.0108309
Oct-84	0.0004857	Nov-87	0.0400088	Jan-91	0.0035307	Feb-94	0.0055906
Nov-84	0.0004576	Dec-87	0.0303825	Feb-91	0.0026551	Mar-94	0.0057207
Dec-84	0.0006381	Jan-88	0.015819	Mar-91	0.0023552	Apr-94	0.0044096
Jan-85	0.0005317	Feb-88	0.0081527	Apr-91	0.0024345	May-94	0.0024258
Feb-85	0.0005747	Mar-88	0.0101805	May-91	0.0028439	Jun-94	0.0017808
Mar-85	0.0008636	Apr-88	0.0052967	Jun-91	0.0018627	Jul-94	0.0036936
Apr-85	0.0014131	May-88	0.0031177	Jul-91	0.0014682	Aug-94	0.0072898
May-85	0.0009728	Jun-88	0.0036462	Aug-91	0.0016388	Sep-94	0.0089007
Jun-85	0.0010597	Jul-88	0.0026187	Sep-91	0.0011557		
Jul-85	0.0009211	Aug-88	0.0019172	Oct-91	0.0023271		
Aug-85	0.0008429	Sep-88	0.0022867	Nov-91	0.0014767		
Sep-85	0.0012485	Oct-88	0.0032191	Dec-91	0.0011865		
		Nov-88	0.0024818				

After the Introduction of Rice Futures Contracts on the CBOT

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Oct-94	0.0018912	Mar-98	0.0012772	Aug-01	0.0017247	Jan-05	0.0019226	Jun-08	0.0030854
Nov-94	0.0019446	Apr-98	0.0012178	Sep-01	0.002197	Feb-05	0.0014812	Jul-08	0.0027426
Dec-94	0.0015305	May-98	0.0013978	Oct-01	0.0027032	Mar-05	0.0023664	Aug-08	0.0020652
Jan-95	0.0013015	Jun-98	0.0012644	Nov-01	0.0025524	Apr-05	0.0017029	Sep-08	0.002828
Feb-95	0.0013622	Jul-98	0.0012623	Dec-01	0.0019913	May-05	0.0013768	Oct-08	0.0026464
Mar-95	0.001273	Aug-98	0.0011863	Jan-02	0.0014944	Jun-05	0.0012206	Nov-08	0.0044376
Apr-95	0.0011948	Sep-98	0.0019934	Feb-02	0.0012546	Jul-05	0.001145	Dec-08	0.0046119
May-95	0.001164	Oct-98	0.0020115	Mar-02	0.001422	Aug-05	0.0011776	Jan-09	0.0034507
Jun-95	0.0011686	Nov-98	0.0015511	Apr-02	0.001618	Sep-05	0.0013949	Feb-09	0.0026734
Jul-95	0.0011764	Dec-98	0.001429	May-02	0.0013417	Oct-05	0.001358	Mar-09	0.0057531
Aug-95	0.0011639	Jan-99	0.0012779	Jun-02	0.0011848	Nov-05	0.0014525	Apr-09	0.0034934
Sep-95	0.0025309	Feb-99	0.0012127	Jul-02	0.0011949	Dec-05	0.0025857	May-09	0.0026372
Oct-95	0.0019365	Mar-99	0.0011593	Aug-02	0.001311	Jan-06	0.0018091	Jun-09	0.0020675
Nov-95	0.0034145	Apr-99	0.0011304	Sep-02	0.0014493	Feb-06	0.0016403	Jul-09	0.0016183
Dec-95	0.0027348	May-99	0.0015519	Oct-02	0.0015486	Mar-06	0.0014681	Aug-09	0.0018196
Jan-96	0.0020494	Jun-99	0.0016387	Nov-02	0.0013306	Apr-06	0.0012775	Sep-09	0.0016851
Feb-96	0.0016117	Jul-99	0.0013573	Dec-02	0.001725	May-06	0.0012093	Oct-09	0.0014375
Mar-96	0.0014332	Aug-99	0.0012126	Jan-03	0.0018928	Jun-06	0.0012549	Nov-09	0.0013879
Apr-96	0.0012688	Sep-99	0.0084033	Feb-03	0.0017399	Jul-06	0.0011929	Dec-09	0.0014402
May-96	0.001302	Oct-99	0.0072155	Mar-03	0.0033988	Aug-06	0.0011522	Jan-10	0.0014104
Jun-96	0.0014755	Nov-99	0.0043431	Apr-03	0.0022258	Sep-06	0.0026616	Feb-10	0.0016487
Jul-96	0.0012932	Dec-99	0.0026368	May-03	0.0026267	Oct-06	0.0019172	Mar-10	0.0014414
Aug-96	0.0012086	Jan-00	0.0018283	Jun-03	0.0022861	Nov-06	0.0031357	Apr-10	0.001552
Sep-96	0.0014034	Feb-00	0.0014597	Jul-03	0.0044193	Dec-06	0.0023618	May-10	0.0013706
Oct-96	0.0012717	Mar-00	0.0013796	Aug-03	0.0027668	Jan-07	0.0017736	Jun-10	0.0014633
Nov-96	0.0013808	Apr-00	0.0013975	Sep-03	0.0046311	Feb-07	0.0014391	Jul-10	0.0017517
Dec-96	0.001371	May-00	0.001328	Oct-03	0.0048044	Mar-07	0.0015015	Aug-10	0.00191
Jan-97	0.0016339	Jun-00	0.0012605	Nov-03	0.0043453	Apr-07	0.001362	Sep-10	0.0032675
Feb-97	0.0013715	Jul-00	0.0011929	Dec-03	0.0042834	May-07	0.0013123	Oct-10	0.0027736
Mar-97	0.0013003	Aug-00	0.0011561	Jan-04	0.0045203	Jun-07	0.0013175	Nov-10	0.0019364
Apr-97	0.0012583	Sep-00	0.001239	Feb-04	0.0027404	Jul-07	0.0012235	Dec-10	0.0021999
May-97	0.0012538	Oct-00	0.0013719	Mar-04	0.0023181	Aug-07	0.0011856	Jan-11	0.0026927
Jun-97	0.0012538	Nov-00	0.0012078	Apr-04	0.0017363	Sep-07	0.0011578	Feb-11	0.0019216
Jul-97	0.0013962	Dec-00	0.0012968	May-04	0.0014753	Oct-07	0.0011717		
Aug-97	0.001284	Jan-01	0.0011803	Jun-04	0.0013858	Nov-07	0.0026609		
Sep-97	0.0012027	Feb-01	0.0012865	Jul-04	0.0019337	Dec-07	0.0025626		
Oct-97	0.0011652	Mar-01	0.0012966	Aug-04	0.0015176	Jan-08	0.0018805		
Nov-97	0.0011596	Apr-01	0.0011888	Sep-04	0.0018827	Feb-08	0.0021238		
Dec-97	0.001192	May-01	0.0011386	Oct-04	0.0021944	Mar-08	0.0016418		
Jan-98	0.0011618	Jun-01	0.001735	Nov-04	0.0041748	Apr-08	0.0018902		
Feb-98	0.0013026	Jul-01	0.0019792	Dec-04	0.0028229	May-08	0.0018693		

Milled Rice

Before the Introduction of Rice Futures Contracts on the CBOT

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Sep-79	0.0041226	Jan-83	0.0009458	May-86	0.0041575	Sep-89	0.0016349	Jan-93	0.0012684
Oct-79	0.0022628	Feb-83	0.0007354	Jun-86	0.036585	Oct-89	0.000916	Feb-93	0.0039818
Nov-79	0.0016281	Mar-83	0.0018097	Jul-86	0.01485	Nov-89	0.000674	Mar-93	0.00227
Dec-79	0.0006763	Apr-83	0.0007826	Aug-86	0.0075986	Dec-89	0.0005043	Apr-93	0.0015416
Jan-80	0.0047892	May-83	0.0008809	Sep-86	0.0073544	Jan-90	0.0004774	May-93	0.0014353
Feb-80	0.0039536	Jun-83	0.0004892	Oct-86	0.0045009	Feb-90	0.0005524	Jun-93	0.0017151
Mar-80	0.0108331	Jul-83	0.0003965	Nov-86	0.0033739	Mar-90	0.0003865	Jul-93	0.0023065
Apr-80	0.0093283	Aug-83	0.000379	Dec-86	0.0029258	Apr-90	0.0004569	Aug-93	0.0021293
May-80	0.0036639	Sep-83	0.0001817	Jan-87	0.0035244	May-90	0.0004991	Sep-93	0.0017912
Jun-80	0.0035218	Oct-83	0.0001171	Feb-87	0.0073282	Jun-90	0.000497	Oct-93	0.0014032
Jul-80	0.0047081	Nov-83	0.0002113	Mar-87	0.0064847	Jul-90	0.0003671	Nov-93	0.023621
Aug-80	0.0028749	Dec-83	0.0001745	Apr-87	0.0050383	Aug-90	0.0004159	Dec-93	0.1208422
Sep-80	0.0011458	Jan-84	0.0001324	May-87	0.0044472	Sep-90	0.0016238	Jan-94	0.0515679
Oct-80	0.0029271	Feb-84	0.0001994	Jun-87	0.0041388	Oct-90	0.0040535	Feb-94	0.0198445
Nov-80	0.0045622	Mar-84	0.0001333	Jul-87	0.0041213	Nov-90	0.0023601	Mar-94	0.0082164
Dec-80	0.004785	Apr-84	0.0000889	Aug-87	0.0037908	Dec-90	0.0015729	Apr-94	0.0031664
Jan-81	0.0056222	May-84	0.0000774	Sep-87	0.0023785	Jan-91	0.001084	May-94	0.002716
Feb-81	0.0021546	Jun-84	0.0001433	Oct-87	0.0105829	Feb-91	0.0009222	Jun-94	0.0054772
Mar-81	0.000876	Jul-84	0.0000928	Nov-87	0.1337221	Mar-91	0.0055773	Jul-94	0.015007
Apr-81	0.0009394	Aug-84	0.0001268	Dec-87	0.059164	Apr-91	0.0024726	Aug-94	0.0184427
May-81	0.0007564	Sep-84	0.0003746	Jan-88	0.0224998	May-91	0.0017754	Sep-94	0.0195466
Jun-81	0.0003682	Oct-84	0.000194	Feb-88	0.0085009	Jun-91	0.0020385		
Jul-81	0.0002902	Nov-84	0.0001513	Mar-88	0.0219036	Jul-91	0.0018853		
Aug-81	0.0002389	Dec-84	0.0005594	Apr-88	0.0084103	Aug-91	0.0009004		
Sep-81	0.0017248	Jan-85	0.0003178	May-88	0.0032112	Sep-91	0.0006381		
Oct-81	0.0028472	Feb-85	0.0001709	Jun-88	0.0102441	Oct-91	0.0003706		
Nov-81	0.0022725	Mar-85	0.0001518	Jul-88	0.0090346	Nov-91	0.0002318		
Dec-81	0.001589	Apr-85	0.0001107	Aug-88	0.0056405	Dec-91	0.0016624		
Jan-82	0.0010574	May-85	0.0001208	Sep-88	0.006261	Jan-92	0.0010336		
Feb-82	0.0009077	Jun-85	0.0001132	Oct-88	0.0092338	Feb-92	0.0004966		
Mar-82	0.0023142	Jul-85	0.0001369	Nov-88	0.0101021	Mar-92	0.0002845		
Apr-82	0.0022632	Aug-85	0.0001486	Dec-88	0.0041441	Apr-92	0.0004903		
May-82	0.0011041	Sep-85	0.0001307	Jan-89	0.0019776	May-92	0.0003532		
Jun-82	0.0005081	Oct-85	0.0001614	Feb-89	0.0011535	Jun-92	0.0011864		
Jul-82	0.0003094	Nov-85	0.0001313	Mar-89	0.0007983	Jul-92	0.0013699		
Aug-82	0.001178	Dec-85	0.0001266	Apr-89	0.0008051	Aug-92	0.0008543		
Sep-82	0.0016561	Jan-86	0.0002144	May-89	0.0005843	Sep-92	0.0005796		
Oct-82	0.0009194	Feb-86	0.0004949	Jun-89	0.0023709	Oct-92	0.0004338		
Nov-82	0.0004175	Mar-86	0.0003108	Jul-89	0.0010919	Nov-92	0.0004399		
Dec-82	0.000359	Apr-86	0.0004554	Aug-89	0.0034928	Dec-92	0.0005828		

After the Introduction of Rice Futures Contracts on the CBOT

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Oct-94	0.0009861	Jan-98	0.000476	Apr-01	0.000617	Jul-04	0.001376	Oct-07	0.000409
Nov-94	0.0010032	Feb-98	0.000456	May-01	0.000623	Aug-04	0.001311	Nov-07	0.000402
Dec-94	0.0009904	Mar-98	0.000437	Jun-01	0.000637	Sep-04	0.001269	Dec-07	0.000409
Jan-95	0.0009792	Apr-98	0.000434	Jul-01	0.000642	Oct-04	0.001333		
Feb-95	0.0009596	May-98	0.000417	Aug-01	0.00065	Nov-04	0.0013		
Mar-95	0.0009425	Jun-98	0.0004	Sep-01	0.000674	Dec-04	0.001255		
Apr-95	0.0009239	Jul-98	0.000385	Oct-01	0.000761	Jan-05	0.001211		
May-95	0.0008981	Aug-98	0.000371	Nov-01	0.0008	Feb-05	0.001166		
Jun-95	0.0009175	Sep-98	0.000358	Dec-01	0.000847	Mar-05	0.001129		
Jul-95	0.0010802	Oct-98	0.000357	Jan-02	0.00092	Apr-05	0.001092		
Aug-95	0.0010498	Nov-98	0.000345	Feb-02	0.000983	May-05	0.00106		
Sep-95	0.0010025	Dec-98	0.000345	Mar-02	0.001066	Jun-05	0.001025		
Oct-95	0.0009632	Jan-99	0.000333	Apr-02	0.001143	Jul-05	0.000993		
Nov-95	0.0010896	Feb-99	0.000327	May-02	0.001214	Aug-05	0.000965		
Dec-95	0.0010378	Mar-99	0.000319	Jun-02	0.001293	Sep-05	0.000939		
Jan-96	0.0010022	Apr-99	0.000314	Jul-02	0.001375	Oct-05	0.000911		
Feb-96	0.0009696	May-99	0.000309	Aug-02	0.00144	Nov-05	0.000885		
Mar-96	0.0009299	Jun-99	0.000326	Sep-02	0.00149	Dec-05	0.000869		
Apr-96	0.0008892	Jul-99	0.000335	Oct-02	0.001565	Jan-06	0.000838		
May-96	0.0008665	Aug-99	0.000334	Nov-02	0.001654	Feb-06	0.000877		
Jun-96	0.000853	Sep-99	0.000346	Dec-02	0.001723	Mar-06	0.000853		
Jul-96	0.0008126	Oct-99	0.000351	Jan-03	0.001777	Apr-06	0.000822		
Aug-96	0.0007732	Nov-99	0.000355	Feb-03	0.001817	May-06	0.000787		
Sep-96	0.0007915	Dec-99	0.000366	Mar-03	0.001859	Jun-06	0.000753		
Oct-96	0.0007552	Jan-00	0.000377	Apr-03	0.001838	Jul-06	0.000722		
Nov-96	0.0008003	Feb-00	0.000404	May-03	0.002057	Aug-06	0.00069		
Dec-96	0.0008017	Mar-00	0.000421	Jun-03	0.002062	Sep-06	0.000693		
Jan-97	0.0007639	Apr-00	0.000442	Jul-03	0.002008	Oct-06	0.000711		
Feb-97	0.0007269	May-00	0.000467	Aug-03	0.001943	Nov-06	0.000678		
Mar-97	0.0007219	Jun-00	0.0005	Sep-03	0.001955	Dec-06	0.000647		
Apr-97	0.0006946	Jul-00	0.000532	Oct-03	0.001899	Jan-07	0.000617		
May-97	0.0006641	Aug-00	0.000556	Nov-03	0.00183	Feb-07	0.000588		
Jun-97	0.0006339	Sep-00	0.000579	Dec-03	0.001774	Mar-07	0.000561		
Jul-97	0.0006037	Oct-00	0.000592	Jan-04	0.001726	Apr-07	0.000537		
Aug-97	0.0005775	Nov-00	0.000608	Feb-04	0.001649	May-07	0.000514		
Sep-97	0.0005515	Dec-00	0.000609	Mar-04	0.001573	Jun-07	0.000491		
Oct-97	0.0005316	Jan-01	0.000611	Apr-04	0.0015	Jul-07	0.000469		
Nov-97	0.0005179	Feb-01	0.000612	May-04	0.001432	Aug-07	0.000448		
Dec-97	0.0004981	Mar-01	0.000614	Jun-04	0.001417	Sep-07	0.000428		

World Rice (Thai 100% B Second Grade)

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Jan-78	0.0038039	May-81	0.0015619	Sep-84	0.0017814	Jan-88	0.0053109	May-91	0.0056669
Feb-78	0.0032594	Jun-81	0.0013632	Oct-84	0.0031604	Feb-88	0.0082689	Jun-91	0.0040759
Mar-78	0.0050708	Jul-81	0.0014306	Nov-84	0.0024427	Mar-88	0.0063135	Jul-91	0.0030758
Apr-78	0.0044706	Aug-81	0.0014389	Dec-84	0.0043256	Apr-88	0.0049808	Aug-91	0.0028018
May-78	0.0035989	Sep-81	0.0019821	Jan-85	0.003293	May-88	0.0037601	Sep-91	0.0024007
Jun-78	0.0027178	Oct-81	0.001799	Feb-85	0.0025018	Jun-88	0.0064208	Oct-91	0.0021468
Jul-78	0.0021793	Nov-81	0.0028374	Mar-85	0.0021444	Jul-88	0.0050636	Nov-91	0.0023672
Aug-78	0.0025218	Dec-81	0.0032813	Apr-85	0.0017423	Aug-88	0.0037388	Dec-91	0.0019368
Sep-78	0.0026003	Jan-82	0.0065978	May-85	0.0014764	Sep-88	0.0029128	Jan-92	0.0016833
Oct-78	0.0020449	Feb-82	0.007477	Jun-85	0.0013005	Oct-88	0.0022891	Feb-92	0.0015368
Nov-78	0.0018732	Mar-82	0.0062121	Jul-85	0.0011849	Nov-88	0.0018387	Mar-92	0.0013452
Dec-78	0.0064945	Apr-82	0.0044313	Aug-85	0.0021511	Dec-88	0.0015494	Apr-92	0.0012229
Jan-79	0.0058551	May-82	0.0037185	Sep-85	0.0017474	Jan-89	0.0019532	May-92	0.0011376
Feb-79	0.0042269	Jun-82	0.0033635	Oct-85	0.0014805	Feb-89	0.0016578	Jun-92	0.0011889
Mar-79	0.0031186	Jul-82	0.0027309	Nov-85	0.0013039	Mar-89	0.001568	Jul-92	0.0013853
Apr-79	0.0028792	Aug-82	0.0021528	Dec-85	0.0011872	Apr-89	0.0014597	Aug-92	0.0017824
May-79	0.002231	Sep-82	0.0017915	Jan-86	0.0022838	May-89	0.0020536	Sep-92	0.0019082
Jun-79	0.0018023	Oct-82	0.0025858	Feb-86	0.0028567	Jun-89	0.0025485	Oct-92	0.0023077
Jul-79	0.0015844	Nov-82	0.003112	Mar-86	0.0027544	Jul-89	0.00296	Nov-92	0.0020331
Aug-79	0.0013827	Dec-82	0.0024266	Apr-86	0.0032823	Aug-89	0.0031192	Dec-92	0.0016754
Sep-79	0.0022798	Jan-83	0.0021364	May-86	0.0037827	Sep-89	0.0032883	Jan-93	0.0014775
Oct-79	0.0020468	Feb-83	0.0019074	Jun-86	0.0028664	Oct-89	0.0028477	Feb-93	0.0014134
Nov-79	0.0016791	Mar-83	0.0019142	Jul-86	0.0022979	Nov-89	0.0030708	Mar-93	0.0015579
Dec-79	0.0014358	Apr-83	0.0020352	Aug-86	0.0058186	Dec-89	0.0062638	Apr-93	0.0041141
Jan-80	0.0016538	May-83	0.0016708	Sep-86	0.0043335	Jan-90	0.0044716	May-93	0.0064303
Feb-80	0.0018176	Jun-83	0.001453	Oct-86	0.0046875	Feb-90	0.0033189	Jun-93	0.0078027
Mar-80	0.0015402	Jul-83	0.0017681	Nov-86	0.0034443	Mar-90	0.0042579	Jul-93	0.0055777
Apr-80	0.0017016	Aug-83	0.0018489	Dec-86	0.0026192	Apr-90	0.0035632	Aug-93	0.0068266
May-80	0.0014616	Sep-83	0.0023091	Jan-87	0.002562	May-90	0.0033081	Sep-93	0.0048394
Jun-80	0.0015344	Oct-83	0.0034609	Feb-87	0.0023029	Jun-90	0.0035438	Oct-93	0.0036499
Jul-80	0.0014243	Nov-83	0.0028479	Mar-87	0.0033547	Jul-90	0.0027953	Nov-93	0.0154693
Aug-80	0.0012668	Dec-83	0.0024005	Apr-87	0.0033357	Aug-90	0.0021722	Dec-93	0.0241592
Sep-80	0.0011626	Jan-84	0.002306	May-87	0.0025307	Sep-90	0.0018043	Jan-94	0.0165033
Oct-80	0.0010937	Feb-84	0.0029036	Jun-87	0.0020121	Oct-90	0.0015273	Feb-94	0.0147085
Nov-80	0.0010482	Mar-84	0.002332	Jul-87	0.0016968	Nov-90	0.0029941	Mar-94	0.0101855
Dec-80	0.0015287	Apr-84	0.001867	Aug-87	0.00166	Dec-90	0.0026315	Apr-94	0.0285152
Jan-81	0.0013754	May-84	0.0015805	Sep-87	0.0024878	Jan-91	0.0023431	May-94	0.0192977
Feb-81	0.0012344	Jun-84	0.0014232	Oct-87	0.0127057	Feb-91	0.0072285	Jun-94	0.0181338
Mar-81	0.0012306	Jul-84	0.001287	Nov-87	0.0097905	Mar-91	0.0061954	Jul-94	0.0143248
Apr-81	0.0017561	Aug-84	0.0021894	Dec-87	0.007531	Apr-91	0.0050771	Aug-94	0.0102819

Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)	Date	GARCH(1,1)
Sep-94	0.0097	Jan-98	0.0032564	May-01	0.0036926	Sep-04	0.0023876	Jan-08	0.0024496
Oct-94	0.0070773	Feb-98	0.0054281	Jun-01	0.0027955	Oct-04	0.001908	Feb-08	0.0023193
Nov-94	0.0050104	Mar-98	0.0039358	Jul-01	0.0022632	Nov-04	0.0015881	Mar-08	0.0123589
Dec-94	0.0036532	Apr-98	0.002949	Aug-01	0.001842	Dec-04	0.0016388	Apr-08	
Jan-95	0.0028234	May-98	0.0029462	Sep-01	0.0015601	Jan-05	0.0022736	May-08	
Feb-95	0.002875	Jun-98	0.002392	Oct-01	0.0014882	Feb-05	0.002109	Jun-08	
Mar-95	0.0026181	Jul-98	0.002249	Nov-01	0.0013668	Mar-05	0.0017508	Jul-08	
Apr-95	0.0021065	Aug-98	0.0020049	Dec-01	0.0012426	Apr-05	0.0014921	Aug-08	0.0280304
May-95	0.0017327	Sep-98	0.0016508	Jan-02	0.0018418	May-05	0.0013444	Sep-08	0.0207093
Jun-95	0.0015693	Oct-98	0.0014233	Feb-02	0.0025287	Jun-05	0.0012768	Oct-08	0.0141608
Jul-95	0.0053413	Nov-98	0.002934	Mar-02	0.0020487	Jul-05	0.00142	Nov-08	0.0155558
Aug-95	0.0046856	Dec-98	0.004972	Apr-02	0.001901	Aug-05	0.0015356	Dec-08	0.0135458
Sep-95	0.003498	Jan-99	0.0040694	May-02	0.0015808	Sep-05	0.001394	Jan-09	0.0094476
Oct-95	0.0033549	Feb-99	0.0040747	Jun-02	0.0018573	Oct-05	0.0012785	Feb-09	0.0096885
Nov-95	0.0034697	Mar-99	0.004601	Jul-02	0.001619	Nov-05	0.0011895	Mar-09	0.0069312
Dec-95	0.0063976	Apr-99	0.0055902	Aug-02	0.0014495	Dec-05	0.0016219	Apr-09	0.0049789
Jan-96	0.004554	May-99	0.0060269	Sep-02	0.0018204	Jan-06	0.0014154	May-09	0.0054255
Feb-96	0.0043946	Jun-99	0.0046153	Oct-02	0.0016087	Feb-06	0.0014002	Jun-09	0.0051381
Mar-96	0.0032348	Jul-99	0.0037916	Nov-02	0.0014791	Mar-06	0.0016459	Jul-09	0.0037585
Apr-96	0.0025215	Aug-99	0.002831	Dec-02	0.001313	Apr-06	0.0014126	Aug-09	0.006945
May-96	0.0051722	Sep-99	0.0023162	Jan-03	0.0012355	May-06	0.0012573	Sep-09	0.0066445
Jun-96	0.003821	Oct-99	0.0034328	Feb-03	0.0025458	Jun-06	0.0011664	Oct-09	0.0049147
Jul-96	0.0030152	Nov-99	0.0040398	Mar-03	0.0020218	Jul-06	0.001131	Nov-09	0.004235
Aug-96	0.0028476	Dec-99	0.0035268	Apr-03	0.0016963	Aug-06	0.0011732	Dec-09	0.0031255
Sep-96	0.0034186	Jan-00	0.0026985	May-03	0.0014807	Sep-06	0.0010991	Jan-10	0.0035254
Oct-96	0.0027366	Feb-00	0.0032833	Jun-03	0.0013313	Oct-06	0.0010545	Feb-10	0.0027214
Nov-96	0.0028361	Mar-00	0.0026108	Jul-03	0.0013983	Nov-06	0.0010657	Mar-10	0.0022888
Dec-96	0.0022044	Apr-00	0.0030991	Aug-03	0.001393	Dec-06	0.0013044	Apr-10	0.0032974
Jan-97	0.0017932	May-00	0.0031932	Sep-03	0.0013303	Jan-07	0.0013655	May-10	0.0041315
Feb-97	0.0056064	Jun-00	0.0046044	Oct-03	0.0014371	Feb-07	0.0012578	Jun-10	0.0044761
Mar-97	0.004242	Jul-00	0.0033819	Nov-03	0.001276	Mar-07	0.0011633	Jul-10	0.0032887
Apr-97	0.0045474	Aug-00	0.002941	Dec-03	0.0012166	Apr-07	0.0013163	Aug-10	0.0025991
May-97	0.0050307	Sep-00	0.0024119	Jan-04	0.001313	May-07	0.0012501	Sep-10	0.0020753
Jun-97	0.005278	Oct-00	0.0026267	Feb-04	0.0018344	Jun-07	0.0011659	Oct-10	0.0024449
Jul-97	0.003825	Nov-00	0.0025885	Mar-04	0.0017029	Jul-07	0.0011542	Nov-10	0.0020065
Aug-97	0.0028943	Dec-00	0.0020774	Apr-04	0.0050999	Aug-07	0.0011585	Dec-10	0.0026044
Sep-97	0.0059701	Jan-01	0.0017213	May-04	0.0043711	Sep-07	0.0010981	Jan-11	0.0024354
Oct-97	0.005103	Feb-01	0.0014626	Jun-04	0.0032396	Oct-07	0.0010625	Feb-11	0.002393
Nov-97	0.0037956	Mar-01	0.0012907	Jul-04	0.0027411	Nov-07	0.0010735	Mar-11	0.0020067
Dec-97	0.0036887	Apr-01	0.0017599	Aug-04	0.002229	Dec-07	0.0019524	Apr-11	0.0025868

Appendix H: Results of Estimating Volatility by GARCH Model (Stata Output)

Estimation of (4.4 and 4.7)

$$r_t = \beta_o + \beta_1 CRB_t + \beta_2 WP_t + \epsilon_t \quad (4.4)$$

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 D_t + \alpha_4 P_t \quad (4.7)$$

Rough Rice

```
. tsset time
        time variable:  time, 1 to 342

. arch spot crb wprtrn, het(dum cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  524.67564
Iteration 1:   log likelihood =  534.30804
Iteration 2:   log likelihood =  541.34092
Iteration 3:   log likelihood =  542.63938
Iteration 4:   log likelihood =  542.81027
(switching optimization to BFGS)
Iteration 5:   log likelihood =  547.41497
Iteration 6:   log likelihood =  548.90147
Iteration 7:   log likelihood =  549.15428
Iteration 8:   log likelihood =  549.15428  (backed up)
Iteration 9:   log likelihood =  549.24244
Iteration 10:  log likelihood =  549.42047
Iteration 11:  log likelihood =  549.44315
Iteration 12:  log likelihood =  549.48556
Iteration 13:  log likelihood =  549.53128
Iteration 14:  log likelihood =  549.53425
(switching optimization to BHHH)
Iteration 15:  log likelihood =   549.5346
Iteration 16:  log likelihood =  549.63989
Iteration 17:  log likelihood =  549.65658
Iteration 18:  log likelihood =  549.66548
Iteration 19:  log likelihood =  549.66933
(switching optimization to BFGS)
Iteration 20:  log likelihood =  549.67367
Iteration 21:  log likelihood =  549.68119
Iteration 22:  log likelihood =   549.6815
Iteration 23:  log likelihood =  549.68178
Iteration 24:  log likelihood =  549.68232
Iteration 25:  log likelihood =  549.68387
Iteration 26:  log likelihood =  549.68389  (backed up)
Iteration 27:  log likelihood =  549.68414
Iteration 28:  log likelihood =  549.68419
Iteration 29:  log likelihood =  549.68424
(switching optimization to BHHH)
Iteration 30:  log likelihood =  549.68426
Iteration 31:  log likelihood =  549.68431
Iteration 32:  log likelihood =  549.68431
Iteration 33:  log likelihood =  549.68433
Iteration 34:  log likelihood =  549.68433
(switching optimization to BFGS)
Iteration 35:  log likelihood =  549.68433  (backed up)
Iteration 36:  log likelihood =  549.68433  (backed up)
Iteration 37:  log likelihood =  549.68433
Iteration 38:  log likelihood =  549.68433  (backed up)
Iteration 39:  log likelihood =  549.68433
Iteration 40:  log likelihood =  549.68433  (backed up)
Iteration 41:  log likelihood =  549.68433  (backed up)
Iteration 42:  log likelihood =  549.68433
Iteration 43:  log likelihood =  549.68433  (backed up)
Iteration 44:  log likelihood =  549.68433  (backed up)
(switching optimization to BHHH)
Iteration 45:  log likelihood =  549.68433  (backed up)
Iteration 46:  log likelihood =  549.68433  (backed up)
Iteration 47:  log likelihood =  549.68433  (backed up)
Iteration 48:  log likelihood =  549.68433  (backed up)
Iteration 49:  log likelihood =  549.68433  (backed up)
(switching optimization to BFGS)
```

```
Iteration 50:  log likelihood =  549.68433  (backed up)
Iteration 51:  log likelihood =  549.68433  (backed up)
Iteration 52:  log likelihood =  549.68433  (backed up)
Iteration 53:  log likelihood =  549.68433  (backed up)
Iteration 54:  log likelihood =  549.68433  (backed up)
Iteration 55:  log likelihood =  549.68433  (backed up)
Iteration 56:  log likelihood =  549.68433  (backed up)
Iteration 57:  log likelihood =  549.68433  (backed up)
Iteration 58:  log likelihood =  549.68433  (backed up)
Iteration 59:  log likelihood =  549.68433  (backed up)
(switching optimization to BHHH)
Iteration 60:  log likelihood =  549.68433  (backed up)
Iteration 61:  log likelihood =  549.68433  (backed up)
Iteration 62:  log likelihood =  549.68433  (backed up)
Iteration 63:  log likelihood =  549.68433  (backed up)
Iteration 64:  log likelihood =  549.68433  (backed up)
(switching optimization to BFGS)
Iteration 65:  log likelihood =  549.68433  (backed up)
Iteration 66:  log likelihood =  549.68433  (backed up)
Iteration 67:  log likelihood =  549.68433  (backed up)
Iteration 68:  log likelihood =  549.68433  (backed up)
Iteration 69:  log likelihood =  549.68433  (backed up)
Iteration 70:  log likelihood =  549.68433  (backed up)
Iteration 71:  log likelihood =  549.68433  (backed up)
Iteration 72:  log likelihood =  549.68433  (backed up)
Iteration 73:  log likelihood =  549.68433  (backed up)
Iteration 74:  log likelihood =  549.68433

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 342                               Number of obs      =       342
                                                Wald chi2(2)       =     12.92
Log likelihood =  549.6843                      Prob > chi2        =    0.0016

------------------------------------------------------------------------------
             |                 OPG
        spot |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
spot         |
         crb |    .035179   .0750278     0.47   0.639    -.1118727    .1822308
      wprtrn |   .0889872   .0258457     3.44   0.001     .0383306    .1396438
       _cons |  -.0008927   .0029301    -0.30   0.761    -.0066356    .0048502
-------------+----------------------------------------------------------------
HET          |
         dum |  -.5124324   .1382895    -3.71   0.000    -.7834748     -.24139
        cash |  -.0049808   .0024909    -2.00   0.046    -.0098629   -.0000986
       _cons |  -5.852786   .3187265   -18.36   0.000    -6.477479   -5.228094
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .4225579   .0860238     4.91   0.000     .2539543    .5911615
       garch |
         L1. |   .3277246   .0848441     3.86   0.000     .1614333     .494016
------------------------------------------------------------------------------
```

Milled Rice

```
. tsset time
        time variable:  time, 1 to 366

. arch milled crb wprtrn, het(dum cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  636.30661
Iteration 1:   log likelihood =  659.23383
Iteration 2:   log likelihood =  668.41137
Iteration 3:   log likelihood =  673.11275
Iteration 4:   log likelihood =  678.05973
(switching optimization to BFGS)
Iteration 5:   log likelihood =  679.60549
Iteration 6:   log likelihood =  680.39368
Iteration 7:   log likelihood =  683.12243
Iteration 8:   log likelihood =   686.7832
Iteration 9:   log likelihood =  688.90191
```

```
Iteration 10:  log likelihood =  690.50595
Iteration 11:  log likelihood =   691.5507
Iteration 12:  log likelihood =  691.79982
Iteration 13:  log likelihood =  692.21058
Iteration 14:  log likelihood =  692.31443
(switching optimization to BHHH)
Iteration 15:  log likelihood =  692.38653
Iteration 16:  log likelihood =  692.43812
Iteration 17:  log likelihood =  692.44464
Iteration 18:  log likelihood =   692.4486
Iteration 19:  log likelihood =  692.45113
(switching optimization to BFGS)
Iteration 20:  log likelihood =   692.4533
Iteration 21:  log likelihood =  692.47041
Iteration 22:  log likelihood =  692.47697
Iteration 23:  log likelihood =  692.48118
Iteration 24:  log likelihood =   692.4826
Iteration 25:  log likelihood =   692.4828
Iteration 26:  log likelihood =  692.48282
Iteration 27:  log likelihood =  692.48282
Iteration 28:  log likelihood =  692.48282

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 366                               Number of obs      =       366
                                                Wald chi2(2)       =     31.37
Log likelihood =  692.4828                      Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |                 OPG
      milled |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
milled       |
         crb |   .1297854    .055997     2.32   0.020     .0200332    .2395375
      wprtrn |   .0820868   .0192359     4.27   0.000     .0443851    .1197884
       _cons |  -.0102783    .001563    -6.58   0.000    -.0133417   -.0072149
-------------+----------------------------------------------------------------
HET          |
         dum |  -.4716149   .1608746    -2.93   0.003    -.7869234   -.1563064
        cash |   .0012217   .0007337     1.67   0.096    -.0002162    .0026597
       _cons |  -7.711668   .3227048   -23.90   0.000    -8.344158   -7.079178
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |    1.19158   .1427916     8.34   0.000     .9117134    1.471446
       garch |
         L1. |   .0041671   .0220867     0.19   0.850    -.0391219    .0474562
------------------------------------------------------------------------------
```

World Rice (Impact of Rice Futures on the CBOT)

```
. arch wprtrn crbrtrn, het(dum) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  592.80672
Iteration 1:   log likelihood =  597.14604
Iteration 2:   log likelihood =  605.37951
Iteration 3:   log likelihood =  610.32706
Iteration 4:   log likelihood =  611.18809
(switching optimization to BFGS)
Iteration 5:   log likelihood =  611.32873
Iteration 6:   log likelihood =  611.40914
Iteration 7:   log likelihood =  611.41736
Iteration 8:   log likelihood =  611.41796
Iteration 9:   log likelihood =  611.41799


ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 400                               Number of obs      =       400
                                                Wald chi2(1)       =      1.06
Log likelihood =   611.418                      Prob > chi2        =    0.3023

------------------------------------------------------------------------------
```

```
             |                 OPG
      wprtrn |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
wprtrn       |
      crbrtrn |    .123953   .1201777     1.03   0.302     -.111591     .359497
       _cons |   .0016475   .0025046     0.66   0.511    -.0032614     .0065564
-------------+----------------------------------------------------------------
HET          |
         dum |  -.2818254   .2436502    -1.16   0.247    -.7593709     .1957202
       _cons |   -7.96268   .3273619   -24.32   0.000    -8.604298    -7.321063
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .2537816   .0420329     6.04   0.000     .1713985     .3361646
       garch |
         L1. |   .6770279   .0425368    15.92   0.000     .5936573     .7603985
```

Estimation of Volatility before and after the Introduction of the Rice Futures on the CBOT

Estimation of (5.1)

$$h_t = \alpha_\circ + \alpha_1 \epsilon_{t-1}^2 + \alpha_2 h_{t-1} + \alpha_3 P_t \qquad (5.1)$$

Rough Rice pre Futures

```
. tsset time
        time variable:  time, 1 to 145

. arch spot crb wprtrn, het(cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =   185.7151  
Iteration 1:   log likelihood =  189.85806  
Iteration 2:   log likelihood =  189.85806  (backed up)
Iteration 3:   log likelihood =   195.8655  
Iteration 4:   log likelihood =  202.94261  
(switching optimization to BFGS)
Iteration 5:   log likelihood =  209.38516  
Iteration 6:   log likelihood =  212.02512  
Iteration 7:   log likelihood =  212.02512  (backed up)
Iteration 8:   log likelihood =  213.90129  
Iteration 9:   log likelihood =  214.93967  
Iteration 10:  log likelihood =  216.52912  
Iteration 11:  log likelihood =  217.11542  
Iteration 12:  log likelihood =  217.47106  
Iteration 13:  log likelihood =  217.67165  
Iteration 14:  log likelihood =  217.78075  
(switching optimization to BHHH)
Iteration 15:  log likelihood =  218.08447  
Iteration 16:  log likelihood =   219.3064  
Iteration 17:  log likelihood =  220.73756  
Iteration 18:  log likelihood =   221.6741  
Iteration 19:  log likelihood =   222.1615  
(switching optimization to BFGS)
Iteration 20:  log likelihood =  222.50483  
Iteration 21:  log likelihood =  222.72384  
Iteration 22:  log likelihood =  222.88762  
Iteration 23:  log likelihood =  222.95527  
Iteration 24:  log likelihood =  222.96176  
Iteration 25:  log likelihood =  222.98784  
Iteration 26:  log likelihood =  222.98817  
Iteration 27:  log likelihood =  223.00069  
Iteration 28:  log likelihood =  223.00459  
Iteration 29:  log likelihood =  223.00476  
(switching optimization to BHHH)
Iteration 30:  log likelihood =  223.00494  
Iteration 31:  log likelihood =  223.00979  
Iteration 32:  log likelihood =  223.00989  
Iteration 33:  log likelihood =  223.01261  
Iteration 34:  log likelihood =  223.01328  
(switching optimization to BFGS)
Iteration 35:  log likelihood =  223.01349  
Iteration 36:  log likelihood =  223.01412  
Iteration 37:  log likelihood =  223.01415  
Iteration 38:  log likelihood =  223.01418  
```

```
Iteration 39:  log likelihood =  223.01419
Iteration 40:  log likelihood =  223.01419
Iteration 41:  log likelihood =  223.01419
Iteration 42:  log likelihood =  223.01419

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 145                                 Number of obs      =       145
                                                  Wald chi2(2)       =     13.91
Log likelihood =  223.0142                        Prob > chi2        =    0.0010

------------------------------------------------------------------------------
             |                 OPG
        spot |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
spot         |
         crb |   .0306101   .1520313     0.20   0.840    -.2673658     .328586
      wprtrn |   .2337961   .0638407     3.66   0.000     .1086707    .3589216
       _cons |  -.0014647    .003421    -0.43   0.669    -.0081697    .0052402
-------------+----------------------------------------------------------------
HET          |
        cash |  -.0472173   .0057529    -8.21   0.000    -.0584927   -.0359418
       _cons |  -.0682407   .7121321    -0.10   0.924    -1.463994    1.327513
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .2400776   .1074041     2.24   0.025     .0295695    .4505857
       garch |
         L1. |   .5111449   .0800673     6.38   0.000     .3542158     .668074
------------------------------------------------------------------------------
```

Rough Rice post Futures

```
. tsset time
        time variable:  time, 1 to 197

. arch spot crb wprtrn, het(cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  342.04218
Iteration 1:   log likelihood =   345.2133
Iteration 2:   log likelihood =  346.35268
Iteration 3:   log likelihood =  346.39511
Iteration 4:   log likelihood =  346.39695
(switching optimization to BFGS)
Iteration 5:   log likelihood =  346.40034
Iteration 6:   log likelihood =  346.41561
Iteration 7:   log likelihood =  346.42034
Iteration 8:   log likelihood =  346.42188
Iteration 9:   log likelihood =  346.42222
Iteration 10:  log likelihood =  346.42225
Iteration 11:  log likelihood =  346.42226

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 197                                 Number of obs      =       197
                                                  Wald chi2(2)       =      3.50
Log likelihood =  346.4223                        Prob > chi2        =    0.1740

------------------------------------------------------------------------------
             |                 OPG
        spot |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
spot         |
         crb |   .0678762   .0954526     0.71   0.477    -.1192076    .2549599
      wprtrn |   .0783801   .0527498     1.49   0.137    -.0250076    .1817679
       _cons |   .0007341   .0034416     0.21   0.831    -.0060113    .0074794
-------------+----------------------------------------------------------------
HET          |
        cash |   .0006997   .0022743     0.31   0.758    -.0037578    .0051573
       _cons |  -7.592031   .6729529   -11.28   0.000    -8.910995   -6.273068
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .2230368    .130504     1.71   0.087    -.0327463    .4788198
```

```
             |                 OPG
        spot |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]

       garch |
         L1. |   .4785565   .2545573     1.88   0.060    -.0203666    .9774796
------------------------------------------------------------------------------
```

Milled Rice pre Futures

```
. tsset time
        time variable:  time, 1 to 181

. arch milled crb wprtrn, het(cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  269.79774
Iteration 1:   log likelihood =  287.79507
Iteration 2:   log likelihood =  289.86851
Iteration 3:   log likelihood =  291.48128
Iteration 4:   log likelihood =  295.17766
(switching optimization to BFGS)
Iteration 5:   log likelihood =  305.20887
Iteration 6:   log likelihood =  316.58162
Iteration 7:   log likelihood =  318.18448
Iteration 8:   log likelihood =  321.56573
Iteration 9:   log likelihood =  329.03388
Iteration 10:  log likelihood =  332.02454
Iteration 11:  log likelihood =  332.57227
Iteration 12:  log likelihood =  333.26637
Iteration 13:  log likelihood =  333.69829
Iteration 14:  log likelihood =  334.00653
(switching optimization to BHHH)
Iteration 15:  log likelihood =  334.90762
Iteration 16:  log likelihood =   337.7614
Iteration 17:  log likelihood =  339.19864
Iteration 18:  log likelihood =  340.06857
Iteration 19:  log likelihood =  340.31456
(switching optimization to BFGS)
Iteration 20:  log likelihood =  340.39954
Iteration 21:  log likelihood =  340.47101
Iteration 22:  log likelihood =   340.4889
Iteration 23:  log likelihood =  340.49219
Iteration 24:  log likelihood =  340.49277
Iteration 25:  log likelihood =  340.49281
Iteration 26:  log likelihood =  340.49281

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 181                               Number of obs      =       181
                                                Wald chi2(2)       =     71.84
Log likelihood =  340.4928                      Prob > chi2        =    0.0000

------------------------------------------------------------------------------
             |                 OPG
      milled |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
milled       |
         crb |   .1213094   .0633392     1.92   0.055    -.0028332     .245452
             |                 OPG
      milled |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
milled
      wprtrn |   .1723618   .0265672     6.49   0.000      .120291    .2244327
       _cons |  -.0014053   .0014687    -0.96   0.339    -.0042839    .0014733
-------------+----------------------------------------------------------------
HET          |
        cash |  -.0238578   .0043449    -5.49   0.000    -.0323736    -.015342
       _cons |  -.2889215   1.397403    -0.21   0.836    -3.027781    2.449938
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |    .899769   .1372182     6.56   0.000     .6308262    1.168712
       garch |
         L1. |   .3775949   .0549957     6.87   0.000     .2698053    .4853844
------------------------------------------------------------------------------
```

Milled rice post Futures

```
*****POST FUTURES**** October 1994 to December 2007
. tsset time
        time variable:  time, 1 to 159

. arch milled crb wprtrn, het(cash) arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =   322.5688
Iteration 1:   log likelihood =   325.6554
Iteration 2:   log likelihood =  327.42804
Iteration 3:   log likelihood =  329.07989
Iteration 4:   log likelihood =  330.97627
(switching optimization to BFGS)
Iteration 5:   log likelihood =  332.54269
Iteration 6:   log likelihood =  332.77856
Iteration 7:   log likelihood =  333.74915
Iteration 8:   log likelihood =  334.92089
Iteration 9:   log likelihood =  335.12921
Iteration 10:  log likelihood =  335.34701
Iteration 11:  log likelihood =  335.69087
Iteration 12:  log likelihood =  335.98004
Iteration 13:  log likelihood =  336.30806
Iteration 14:  log likelihood =  336.35333
(switching optimization to BHHH)
Iteration 15:  log likelihood =  336.52425
Iteration 16:  log likelihood =  336.67211
Iteration 17:  log likelihood =  336.68899
Iteration 18:  log likelihood =   336.6908
Iteration 19:  log likelihood =   336.6911
(switching optimization to BFGS)
Iteration 20:  log likelihood =   336.6912
Iteration 21:  log likelihood =  336.69124
Iteration 22:  log likelihood =  336.69124
Iteration 23:  log likelihood =  336.69124

ARCH family regression -- multiplicative heteroskedasticity

Sample:  1 to 159                                 Number of obs      =       159
                                                  Wald chi2(2)       =     15.16
Log likelihood =  336.6912                        Prob > chi2        =    0.0005

------------------------------------------------------------------------------
             |                 OPG
      milled |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
milled       |
         crb |    .153215   .0936955     1.64   0.102    -.0304248    .3368548
      wprtrn |   .1201143   .0415242     2.89   0.004     .0387284    .2015001
       _cons |  -.0020257     .00218    -0.93   0.353    -.0062984    .0022471
-------------+----------------------------------------------------------------
HET          |
        cash |  -.0179978   .0072617    -2.48   0.013    -.0322304   -.0037652

             |                 OPG
      milled |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
HET
       _cons |  -4.986346   1.676782    -2.97   0.003    -8.272778   -1.699915
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .0142886   .0113278     1.26   0.207    -.0079135    .0364906
       garch |
         L1. |   .9494134   .0199533    47.58   0.000     .9103057    .9885211
------------------------------------------------------------------------------
```

World Price before Zhengzhou Rice Futures Market

Estimation of equations (5.2) and (4.6):

$$r_t = \beta_o + \beta_1 CRB_t + \epsilon_t \quad (5.2)$$

$$h_t = a_0 + a_1 \epsilon_{t-1} + b_1 h_{t-1} \quad (4.6)$$

```
********************2003-2005****************************
        time variable:  time, 1 to 104

. arch wp crb, arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  269.87445
Iteration 1:   log likelihood =  270.98982
Iteration 2:   log likelihood =  273.94391
Iteration 3:   log likelihood =  274.43796
Iteration 4:   log likelihood =   274.5061
(switching optimization to BFGS)
Iteration 5:   log likelihood =  274.58357
Iteration 6:   log likelihood =  274.78988
Iteration 7:   log likelihood =  274.82075
Iteration 8:   log likelihood =  274.85599
Iteration 9:   log likelihood =  274.87199
Iteration 10:  log likelihood =  274.87245
Iteration 11:  log likelihood =  274.87247

ARCH family regression

Sample:  1 to 104                               Number of obs      =       104
                                                Wald chi2(1)       =      9.71
Log likelihood =  274.8725                      Prob > chi2        =    0.0018

------------------------------------------------------------------------------
             |                 OPG
          wp |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
wp           |
         crb |   .5410251   .1736509     3.12   0.002     .2006755    .8813747
       _cons |   .0035222   .0016648     2.12   0.034     .0002593    .0067852
-------------+----------------------------------------------------------------
ARCH         |
        arch |
         L1. |   .3643266   .1116529     3.26   0.001      .145491    .5831622
       garch |
         L1. |   -.096395   .1908426    -0.51   0.613    -.4704396    .2776496
       _cons |    .000254   .0000726     3.50   0.000     .0001118    .0003962
------------------------------------------------------------------------------
```

World Price after Zhengzhou Rice Futures Market

Estimation of equations (5.2) and (4.6):

$$r_t = \beta_o + \beta_1 CRB_t + \epsilon_t \qquad (5.2)$$

$$h_t = a_0 + a_1\epsilon_{t-1} + b_1 h_{t-1} \qquad (4.6)$$

```
. tsset time
        time variable:  time, 1 to 104

. arch wp crb, arch(1) garch(1)

(setting optimization to BHHH)
Iteration 0:   log likelihood =  259.76399
Iteration 1:   log likelihood =  260.68565
Iteration 2:   log likelihood =  261.00538
Iteration 3:   log likelihood =  261.06492
Iteration 4:   log likelihood =  261.08911
(switching optimization to BFGS)
Iteration 5:   log likelihood =  261.26828
Iteration 6:   log likelihood =  261.34244
Iteration 7:   log likelihood =  261.34577
Iteration 8:   log likelihood =  261.34602
Iteration 9:   log likelihood =  261.34604

ARCH family regression

Sample:  1 to 104                               Number of obs      =       104
                                                Wald chi2(1)       =      0.33
Log likelihood =   261.346                      Prob > chi2        =    0.5647
```

wp	Coef.	OPG Std. Err.	z	P>|z|	[95% Conf. Interval]	
wp						
crb	.097071	.1685686	0.58	0.565	-.2333174	.4274594
_cons	-.0027701	.0026134	-1.06	0.289	-.0078922	.002352
ARCH						
arch						
L1.	.190394	.1413746	1.35	0.178	-.0866952	.4674832
garch						
L1.	.4661546	.3549539	1.31	0.189	-.2295423	1.161851
_cons	.0001372	.0001164	1.18	0.238	-.0000909	.0003654

Appendix I: Correlation between the Change in US and World Rice Price before and after Rice Futures on the CBOT

Table I. 1: Rough Rice Price and World Price Correlation

FD		P3		CMA	
Pre	Post	Pre	Post	Pre	Post
0.419	0.101	0.738	0.727	0.280	0.098

Table I. 2: Milled Rice Price and and World Price Correlation

FD		P3		CMA	
Pre	Post	Pre	Post	Pre	Post
0.455	0.495	0.708	0.703	0.290	0.361

The prices are detrended using the three methods outlined in chapter 4. Change in rough rice prices are clearly less correlated with the world price after the introduction of the rice futures market on the CBOT. It seems that the change in world prices has less effect on the US rough rice prices and is not transmitted to the US market post introduction of the futures market. This could be another factor contributing to the reduction of rough rice price volatility post futures market. The rice futures market in United States reduces the transmission of world price volatility to the domestic market. Therefore, reducing the part of rice price volatility in United States that is attributable to the volatility in world prices.

The correlation between changes in milled rice price and the world price of rice shows a slight increase post futures market. This could be an indication that rice futures market in United States does not isolate the milled rice market from the world market. The higher correlation value could be due to the recent (2007-08) high volatility in world rice prices that have been transmitted to the milled rice market. More frequent and larger changes in world rice prices imply more action and changes in the milled rice prices and hence the higher correlation post futures.

Appendix J: Results of Granger Causality, Impulse Response Analysis, and Forecast Error Variance Decomposition from Stata

Rough Rice

Granger Causality (FD Method)

```
. var garchr fdvol fdoi, lags(1/5)

Vector autoregression

Sample:       6      130                        No. of obs      =       125
Log likelihood =  675.5257                      AIC             = -10.04041
FPE            =  8.79e-09                      HQIC            = -9.599197
Det(Sigma_ml)  =  4.06e-09                      SBIC            = -8.954338

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
garchr               16     .001191   0.4989   124.4592   0.0000
fdvol                16     .406959   0.5256   138.5008   0.0000
fdoi                 16     .162957   0.1252   17.88271   0.2689
----------------------------------------------------------------
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
garchr       |
      garchr |
         L1. |   .4421465   .0884207     5.00   0.000      .268845    .6154479
         L2. |     .11995    .094697     1.27   0.205    -.0656527    .3055527
         L3. |   .0718118   .0945208     0.76   0.447    -.1134456    .2570692
         L4. |   .1539765     .09102     1.69   0.091    -.0244194    .3323725
         L5. |  -.1333496    .083307    -1.60   0.109    -.2966283    .0299291
       fdvol |
         L1. |   .0006245   .0002588     2.41   0.016     .0001172    .0011318
         L2. |   .0002142   .0002328     0.92   0.357     -.000242    .0006704
         L3. |  -.0004403   .0002161    -2.04   0.042    -.0008639   -.0000167
         L4. |  -.0001529   .0002189    -0.70   0.485    -.0005819    .0002761
         L5. |  -.0001456   .0002237    -0.65   0.515    -.0005841    .0002928
        fdoi |
         L1. |   .0009826   .0006464     1.52   0.128    -.0002843    .0022496
         L2. |   -.002444   .0006716    -3.64   0.000    -.0037603   -.0011277
         L3. |   .0001443   .0007024     0.21   0.837    -.0012324    .0015209
         L4. |  -.0018699   .0007134    -2.62   0.009    -.0032682   -.0004717
         L5. |  -.0004695   .0007266    -0.65   0.518    -.0018937    .0009547
       _cons |   .0009197   .0002589     3.55   0.000     .0004123    .0014271
-------------+----------------------------------------------------------------
fdvol        |
      garchr |
         L1. |   2.945676   30.21383     0.10   0.922    -56.27233    62.16369
         L2. |   .0243947   32.35846     0.00   0.999    -63.39701     63.4458
         L3. |  -30.36615   32.29826    -0.94   0.347    -93.66957    32.93727
         L4. |   11.71073   31.10201     0.38   0.707    -49.24809    72.66955
         L5. |   4.323115   28.46643     0.15   0.879    -51.47006    60.11629
       fdvol |
         L1. |  -.3311274   .0884356    -3.74   0.000     -.504458   -.1577967
         L2. |   .0808125   .0795422     1.02   0.310    -.0750874    .2367124
         L3. |  -.0594888   .0738542    -0.81   0.421    -.2042403    .0852627
         L4. |   .3010099   .0747993     4.02   0.000      .154406    .4476139
         L5. |   .1279558   .0764412     1.67   0.094    -.0218662    .2777778
        fdoi |
         L1. |   .7372156   .2208781     3.34   0.001     .3043025    1.170129
         L2. |  -.2682684    .229489    -1.17   0.242    -.7180587    .1815219
         L3. |   .7555426   .2400088     3.15   0.002     .2851341    1.225951
         L4. |  -.5269109   .2437731    -2.16   0.031    -1.004698   -.0491243
         L5. |  -.1492747   .2482953    -0.60   0.548    -.6359246    .3373752
       _cons |   .1440533    .088469     1.63   0.103    -.0293427    .3174493
```

```
                    Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
fdoi         |
      garchr |
         L1. |  -12.30073   12.09839    -1.02   0.309    -36.01313    11.41168
         L2. |   23.19322   12.95715     1.79   0.073    -2.202331    48.58877
         L3. |   5.454734   12.93305     0.42   0.673    -19.89357    30.80304
         L4. |  -24.43042   12.45404    -1.96   0.050    -48.83989   -.0209507
         L5. |   11.50206   11.39869     1.01   0.313    -10.83895    33.84308
       fdvol |
         L1. |  -.0294766   .0354119    -0.83   0.405    -.0988826    .0399294
         L2. |  -.0057484   .0318507    -0.18   0.857    -.0681747    .0566779
         L3. |   .0035379   .0295731     0.12   0.905    -.0544243    .0615001
         L4. |  -.0454095   .0299516    -1.52   0.129    -.1041134    .0132945
         L5. |   .0122882    .030609     0.40   0.688    -.0477043    .0722808
        fdoi |
         L1. |   .1670226   .0884452     1.89   0.059    -.0063269    .3403721
         L2. |   -.015609   .0918933    -0.17   0.865    -.1957166    .1644985
         L3. |  -.0997128   .0961056    -1.04   0.299    -.2880764    .0886508
         L4. |   .1864804    .097613     1.91   0.056    -.0048375    .3777984
         L5. |  -.0440031   .0994238    -0.44   0.658    -.2388702    .1508639
       _cons |   .0253242   .0354252     0.71   0.475     -.044108    .0947563
------------------------------------------------------------------------------

. vargranger

   Granger causality Wald tests
  +------------------------------------------------------------------+
  |          Equation           Excluded |   chi2     df Prob > chi2 |
  |--------------------------------------+---------------------------|
  |            garchr              fdvol |  9.8948     5    0.078    |
  |            garchr               fdoi |   22.75     5    0.000    |
  |            garchr                ALL |  30.791    10    0.001    |
  |--------------------------------------+---------------------------|
  |             fdvol             garchr |   1.068     5    0.957    |
  |             fdvol               fdoi |  25.246     5    0.000    |
  |             fdvol                ALL |  28.329    10    0.002    |
  |--------------------------------------+---------------------------|
  |              fdoi             garchr |   6.709     5    0.243    |
  |              fdoi              fdvol |  4.1229     5    0.532    |
  |              fdoi                ALL |  10.362    10    0.409    |
  +------------------------------------------------------------------+
```

Impulse Response and FEVD (FD Method)

```
. irf ctable (fdr garchr garchr fevd, noci) (fdr fdvol garchr fevd, noci) (fdr fdoi garchr fevd, noci) (fdr
> garchr garchr irf, noci) (fdr fdvol garchr irf, noci) (fdr fdoi garchr irf, noci)
```

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
0	0	0	0	1	0	0
1	1	0	0	.442146	.000624	.000983
2	.945951	.039631	.014418	.305196	.000255	-.001385
3	.921734	.039602	.038664	.300381	-.000154	-.000863
4	.916231	.038918	.044851	.319591	-.000023	-.002187
5	.874264	.034565	.091171	.108821	.000104	-.001816
6	.845378	.033267	.121355	.118747	.00016	-.002154
7	.808108	.03205	.159842	.072154	-.000102	-.000906
8	.801674	.0326	.165726	.0535	.000065	-.001253
9	.790149	.0321	.177752	.013269	.000013	-.000538
10	.788029	.032006	.179966	.031058	.000118	-.000868
11	.782204	.032275	.185521	.001031	-.000043	-.000108
12	.782023	.032391	.185586	.002025	.000064	-.000425
13	.780577	.032498	.186925	-.008094	-.000023	.000058
14	.78054	.032521	.186939	.006292	.000074	-.000319
15	.77961	.032732	.187657	-.008154	-.000029	.00013
16	.779465	.032765	.187771	-.00163	.000046	-.000168
17	.779177	.032856	.187967	-.007803	-.00003	.000165
18	.778958	.032884	.188157	.00262	.000045	-.00015
19	.778718	.032974	.188308	-.005391	-.000026	.000142
20	.778554	.032994	.188452	.000745	.000033	-.000107
21	.77843	.033041	.188529	-.004706	-.000027	.000137
22	.778274	.033065	.188661	.002332	.000029	-.0001
23	.77817	.033101	.188729	-.00305	-.000022	.000108
24	.778071	.033118	.188811	.001795	.000023	-.000086
25	.777998	.033141	.188862	-.002779	-.000021	.000096
26	.777916	.033157	.188927	.002005	.00002	-.000077

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
27	.777858	.033174	.188968	-.001948	-.000017	.000078
28	.777805	.033185	.18901	.001754	.000017	-.000069
29	.777761	.033197	.189043	-.001811	-.000016	.000068
30	.777719	.033206	.189075	.001562	.000015	-.000059
31	.777686	.033215	.1891	-.00141	-.000013	.000057
32	.777657	.033222	.189122	.001393	.000013	-.000053
33	.777631	.033228	.189141	-.001282	-.000012	.000049
34	.777609	.033233	.189158	.001171	.000011	-.000045
35	.77759	.033238	.189172	-.001068	-.00001	.000042
36	.777574	.033242	.189184	.00104	9.4e-06	-.000039
37	.77756	.033245	.189195	-.000943	-8.7e-06	.000036
38	.777547	.033248	.189204	.000872	8.0e-06	-.000034
39	.777537	.033251	.189212	-.000809	-7.5e-06	.000031
40	.777528	.033253	.189219	.000767	7.0e-06	-.000029
41	.77752	.033255	.189225	-.000701	-6.5e-06	.000027
42	.777513	.033257	.18923	.00065	6.0e-06	-.000025
43	.777507	.033258	.189235	-.000608	-5.6e-06	.000023
44	.777502	.033259	.189238	.000567	5.2e-06	-.000022
45	.777498	.03326	.189242	-.000523	-4.8e-06	.00002
46	.777494	.033261	.189244	.000486	4.5e-06	-.000019
47	.777491	.033262	.189247	-.000454	-4.2e-06	.000017
48	.777488	.033263	.189249	.000421	3.9e-06	-.000016
49	.777486	.033263	.189251	-.00039	-3.6e-06	.000015
50	.777484	.033264	.189252	.000363	3.3e-06	-.000014
51	.777482	.033264	.189254	-.000338	-3.1e-06	.000013
52	.77748	.033265	.189255	.000313	2.9e-06	-.000012
53	.777479	.033265	.189256	-.000291	-2.7e-06	.000011
54	.777478	.033265	.189257	.000271	2.5e-06	-.00001
55	.777477	.033265	.189258	-.000252	-2.3e-06	9.7e-06
56	.777476	.033266	.189258	.000233	2.2e-06	-9.0e-06
57	.777475	.033266	.189259	-.000217	-2.0e-06	8.4e-06
58	.777475	.033266	.189259	.000202	1.9e-06	-7.8e-06
59	.777474	.033266	.18926	-.000187	-1.7e-06	7.2e-06
60	.777474	.033266	.18926	.000174	1.6e-06	-6.7e-06
61	.777473	.033266	.18926	-.000162	-1.5e-06	6.2e-06
62	.777473	.033266	.189261	.00015	1.4e-06	-5.8e-06
63	.777473	.033267	.189261	-.00014	-1.3e-06	5.4e-06
64	.777472	.033267	.189261	.00013	1.2e-06	-5.0e-06
65	.777472	.033267	.189261	-.000121	-1.1e-06	4.6e-06
66	.777472	.033267	.189261	.000112	1.0e-06	-4.3e-06
67	.777472	.033267	.189262	-.000104	-9.6e-07	4.0e-06
68	.777472	.033267	.189262	.000097	8.9e-07	-3.7e-06
69	.777471	.033267	.189262	-.00009	-8.3e-07	3.5e-06
70	.777471	.033267	.189262	.000083	7.7e-07	-3.2e-06
71	.777471	.033267	.189262	-.000078	-7.1e-07	3.0e-06
72	.777471	.033267	.189262	.000072	6.6e-07	-2.8e-06
73	.777471	.033267	.189262	-.000067	-6.2e-07	2.6e-06
74	.777471	.033267	.189262	.000062	5.7e-07	-2.4e-06
75	.777471	.033267	.189262	-.000058	-5.3e-07	2.2e-06
76	.777471	.033267	.189262	.000054	5.0e-07	-2.1e-06
77	.777471	.033267	.189262	-.00005	-4.6e-07	1.9e-06
78	.777471	.033267	.189262	.000046	4.3e-07	-1.8e-06
79	.777471	.033267	.189262	-.000043	-4.0e-07	1.7e-06
80	.777471	.033267	.189262	.00004	3.7e-07	-1.5e-06
81	.777471	.033267	.189262	-.000037	-3.4e-07	1.4e-06
82	.777471	.033267	.189262	.000035	3.2e-07	-1.3e-06
83	.777471	.033267	.189262	-.000032	-3.0e-07	1.2e-06
84	.777471	.033267	.189262	.00003	2.8e-07	-1.2e-06
85	.777471	.033267	.189262	-.000028	-2.6e-07	1.1e-06
86	.777471	.033267	.189262	.000026	2.4e-07	-9.9e-07
87	.777471	.033267	.189262	-.000024	-2.2e-07	9.2e-07
88	.777471	.033267	.189262	.000022	2.0e-07	-8.6e-07
89	.777471	.033267	.189262	-.000021	-1.9e-07	8.0e-07
90	.777471	.033267	.189262	.000019	1.8e-07	-7.4e-07
91	.777471	.033267	.189262	-.000018	-1.6e-07	6.9e-07
92	.777471	.033267	.189262	.000017	1.5e-07	-6.4e-07
93	.777471	.033267	.189262	-.000015	-1.4e-07	5.9e-07
94	.777471	.033267	.189262	.000014	1.3e-07	-5.5e-07
95	.777471	.033267	.189262	-.000013	-1.2e-07	5.1e-07
96	.777471	.033267	.189262	.000012	1.1e-07	-4.8e-07
97	.777471	.033267	.189262	-.000011	-1.1e-07	4.4e-07
98	.777471	.033267	.189262	.000011	9.8e-08	-4.1e-07
99	.777471	.033267	.189262	-9.9e-06	-9.1e-08	3.8e-07
100	.777471	.033267	.189262	9.2e-06	8.5e-08	-3.5e-07

Granger Causality (P3 Method)

```
. tsset time
        time variable:  time, 1 to 131

. irf set p3r
(file p3r.irf created)
(file p3r.irf now active)

. var garchr p3vol p3oi, lags(1/5)

Vector autoregression
```

Sample:	6 131	No. of obs	= 126
Log likelihood =	713.0889	AIC	= -10.55697
FPE =	5.24e-09	HQIC	= -10.118
Det(Sigma_ml) =	2.44e-09	SBIC	= -9.476478

Equation	Parms	RMSE	R-sq	chi2	P>chi2
garchr	16	.001211	0.4788	115.7411	0.0000
p3vol	16	.361363	0.3705	74.15863	0.0000
p3oi	16	.139196	0.8481	703.6929	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
garchr						
garchr						
L1.	.4592553	.0848247	5.41	0.000	.2930019	.6255086
L2.	.1200236	.092667	1.30	0.195	-.0616003	.3016476
L3.	.0748445	.0906909	0.83	0.409	-.1029063	.2525953
L4.	.1517996	.0893151	1.70	0.089	-.0232548	.326854
L5.	-.1434951	.083025	-1.73	0.084	-.3062211	.019231
p3vol						
L1.	.0003001	.0002301	1.30	0.192	-.000151	.0007511
L2.	-.0000803	.0002135	-0.38	0.707	-.0004986	.0003381
L3.	-.0003536	.0002088	-1.69	0.090	-.0007628	.0000556
L4.	.0001756	.0002062	0.85	0.394	-.0002285	.0005797
L5.	.0000819	.0002003	0.41	0.683	-.0003106	.0004744
p3oi						
L1.	.0007723	.0007485	1.03	0.302	-.0006947	.0022394
L2.	-.0032015	.001138	-2.81	0.005	-.0054318	-.0009711
L3.	.0033311	.0011786	2.83	0.005	.001021	.0056411
L4.	-.0030876	.001197	-2.58	0.010	-.0054337	-.0007415
L5.	.0024727	.0008136	3.04	0.002	.0008781	.0040673
_cons	.0008287	.000228	3.63	0.000	.0003818	.0012756
p3vol						
garchr						
L1.	-10.13995	25.3214	-0.40	0.689	-59.76899	39.4891
L2.	11.94606	27.66244	0.43	0.666	-42.27134	66.16345
L3.	-20.44368	27.07254	-0.76	0.450	-73.50489	32.61752
L4.	19.69729	26.66186	0.74	0.460	-32.559	71.95357
L5.	12.22666	24.78418	0.49	0.622	-36.34944	60.80276
p3vol						
L1.	.2186745	.0686925	3.18	0.001	.0840396	.3533094
L2.	.1697336	.063719	2.66	0.008	.0448466	.2946206
L3.	-.0012202	.0623223	-0.02	0.984	-.1233696	.1209293
L4.	.1425515	.0615483	2.32	0.021	.021919	.263184
L5.	-.0069046	.059784	-0.12	0.908	-.1240791	.1102699
p3oi						
L1.	.781757	.2234439	3.50	0.000	.3438149	1.219699
L2.	-.7696456	.339696	-2.27	0.023	-1.435437	-.1038537
L3.	1.107517	.3518303	3.15	0.002	.417942	1.797091
L4.	-1.378116	.357322	-3.86	0.000	-2.078454	-.6777781
L5.	.6119483	.2428741	2.52	0.012	.1359239	1.087973
_cons	-.0285156	.068066	-0.42	0.675	-.1619226	.1048913
p3oi						
garchr						
L1.	-9.98707	9.753724	-1.02	0.306	-29.10402	9.129878
L2.	11.85343	10.65549	1.11	0.266	-9.030938	32.7378
L3.	3.010599	10.42826	0.29	0.773	-17.42841	23.44961
L4.	-19.53252	10.27006	-1.90	0.057	-39.66148	.5964313
L5.	7.517569	9.546788	0.79	0.431	-11.19379	26.22893
p3vol						
L1.	-.057965	.0264601	-2.19	0.028	-.1098259	-.006104
L2.	-.0217965	.0245444	-0.89	0.375	-.0699026	.0263095
L3.	.0039916	.0240064	0.17	0.868	-.04306	.0510432
L4.	-.0018267	.0237082	-0.08	0.939	-.048294	.0446405
L5.	.0143088	.0230286	0.62	0.534	-.0308265	.059444

```
                 Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
       p3oi |
        L1. |    1.10643   .0860699    12.86   0.000     .9377363    1.275124
        L2. |  -.2211061   .1308498    -1.69   0.091     -.477567    .0353548
        L3. |  -.1107649   .1355239    -0.82   0.414    -.3763869     .154857
        L4. |   .4242464   .1376393     3.08   0.002     .1544784    .6940145
        L5. |  -.3219079   .0935543    -3.44   0.001     -.505271   -.1385447
      _cons |   .0129296   .0262188     0.49   0.622    -.0384583    .0643176
------------------------------------------------------------------------------

. vargranger

   Granger causality Wald tests
  +------------------------------------------------------------------+
  |          Equation           Excluded |   chi2     df Prob > chi2 |
  |--------------------------------------+---------------------------|
  |            garchr              p3vol |  5.143      5    0.399     |
  |            garchr               p3oi |  18.516     5    0.002     |
  |            garchr                ALL |  24.738    10    0.006     |
  |--------------------------------------+---------------------------|
  |             p3vol             garchr |  1.7031     5    0.889     |
  |             p3vol               p3oi |  36.944     5    0.000     |
  |             p3vol                ALL |  41.157    10    0.000     |
  |--------------------------------------+---------------------------|
  |              p3oi             garchr |  4.9598     5    0.421     |
  |              p3oi              p3vol |  5.6614     5    0.341     |
  |              p3oi                ALL |  10.705    10    0.381     |
  +------------------------------------------------------------------+
```

Impulse Response and FEVD (P3 Method)

```
. irf ctable (p3r garchr garchr fevd, noci) (p3r p3vol garchr fevd, noci) (p3r p3oi garchr fevd, noci) (p3r
> garchr garchr irf, noci) (p3r p3vol garchr irf, noci) (p3r p3oi garchr irf, noci)
```

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
0	0	0	0	1	0	0
1	1	0	0	.459255	.0003	.000772
2	.988175	.005446	.006378	.320183	.000078	-.001758
3	.958458	.006132	.03541	.30651	-.000141	-.000177
4	.959816	.00684	.033344	.344863	.000113	-.002077
5	.927508	.00796	.064532	.145095	.000288	-.00046
6	.922235	.012732	.065033	.139785	.000178	-.000792
7	.916533	.014718	.068749	.091939	.000078	.00087
8	.911544	.014676	.073779	.093974	.000081	.000164
9	.911539	.014889	.073572	.040372	.000036	.001073
10	.903728	.014742	.08153	.048993	-.000014	.000813
11	.899333	.014732	.085935	.013053	-.000064	.001604
12	.881739	.015138	.103123	.018453	-.00009	.001127
13	.872931	.01579	.111279	-.001037	-.000121	.001412
14	.859286	.01692	.123794	.002255	-.000124	.001012
15	.852011	.017988	.130001	-.017731	-.000132	.001224
16	.841842	.019208	.13895	-.013192	-.00013	.000831
17	.836809	.020269	.142923	-.021863	-.000127	.000849
18	.831702	.021274	.147024	-.018047	-.000109	.000504
19	.829637	.021968	.148395	-.02557	-.000097	.000519
20	.82763	.022526	.149844	-.020576	-.000081	.000254
21	.82698	.02288	.15014	-.022696	-.000068	.00023
22	.826499	.023125	.150375	-.017585	-.00005	.000021
23	.826424	.023238	.150338	-.018591	-.000036	.000017
24	.826399	.023297	.150305	-.013732	-.000023	-.000116
25	.826326	.023308	.150366	-.013007	-.000013	-.000111
26	.82627	.023308	.150423	-.008533	-2.1e-06	-.000199
27	.826052	.023301	.150647	-.007652	5.0e-06	-.000177
28	.825877	.023301	.150822	-.004173	.000011	-.000219
29	.825595	.023309	.151096	-.003232	.000015	-.000185
30	.825384	.023324	.151292	-.000514	.000018	-.000203
31	.825128	.023345	.151527	.000081	.000019	-.000164
32	.824952	.023369	.151679	.001826	.00002	-.000163
33	.824778	.023393	.151829	.002052	.000019	-.000123
34	.824672	.023415	.151913	.003123	.000018	-.000114
35	.824582	.023434	.151984	.003015	.000016	-.000079
36	.824534	.023448	.152018	.003476	.000014	-.000067
37	.8245	.023459	.152041	.00311	.000011	-.000038
38	.824486	.023466	.152047	.003203	9.3e-06	-.000027
39	.824479	.023471	.15205	.002709	7.0e-06	-5.7e-06
40	.824477	.023473	.152049	.002561	5.0e-06	1.4e-06
41	.824477	.023474	.152049	.002021	3.1e-06	.000016
42	.824476	.023475	.15205	.001776	1.6e-06	.000019

43	.824474	.023474	.152052	.00128	1.8e-07	.000027
44	.82447	.023474	.152056	.001023	-8.5e-07	.000027
45	.824466	.023474	.15206	.000607	-1.7e-06	.000031

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
46	.82446	.023475	.152065	.000394	-2.3e-06	.000028
47	.824455	.023475	.15207	.000087	-2.7e-06	.000028
48	.82445	.023475	.152074	-.000057	-2.8e-06	.000024
49	.824446	.023476	.152078	-.000259	-2.8e-06	.000023
50	.824443	.023476	.152081	-.000333	-2.7e-06	.000018
51	.824441	.023477	.152082	-.000442	-2.5e-06	.000016
52	.824439	.023477	.152084	-.000455	-2.3e-06	.000011
53	.824438	.023477	.152084	-.000493	-2.0e-06	9.0e-06
54	.824437	.023478	.152085	-.000462	-1.6e-06	5.5e-06
55	.824437	.023478	.152085	-.000452	-1.3e-06	3.4e-06
56	.824437	.023478	.152085	-.000396	-9.9e-07	8.2e-07
57	.824437	.023478	.152085	-.000359	-7.0e-07	-5.8e-07
58	.824437	.023478	.152085	-.000294	-4.3e-07	-2.3e-06
59	.824437	.023478	.152085	-.000247	-2.0e-07	-3.0e-06
60	.824437	.023478	.152085	-.000184	-9.0e-09	-3.9e-06
61	.824437	.023478	.152085	-.000139	1.4e-07	-4.1e-06
62	.824437	.023478	.152085	-.000087	2.6e-07	-4.4e-06
63	.824437	.023478	.152085	-.00005	3.4e-07	-4.1e-06
64	.824436	.023478	.152086	-.000011	3.9e-07	-4.0e-06
65	.824436	.023478	.152086	.000013	4.1e-07	-3.5e-06
66	.824436	.023478	.152086	.000038	4.1e-07	-3.2e-06
67	.824436	.023478	.152086	.000051	3.9e-07	-2.6e-06
68	.824436	.023478	.152086	.000064	3.7e-07	-2.2e-06
69	.824436	.023478	.152086	.000068	3.3e-07	-1.6e-06
70	.824436	.023478	.152086	.000071	2.8e-07	-1.2e-06
71	.824436	.023478	.152086	.000068	2.3e-07	-7.7e-07
72	.824436	.023478	.152086	.000065	1.9e-07	-4.4e-07
73	.824436	.023478	.152086	.000057	1.4e-07	-1.0e-07
74	.824436	.023478	.152086	.000051	9.7e-08	1.2e-07
75	.824436	.023478	.152086	.000042	5.8e-08	3.4e-07
76	.824436	.023478	.152086	.000035	2.6e-08	4.6e-07
77	.824436	.023478	.152086	.000026	-1.3e-09	5.7e-07
78	.824436	.023478	.152086	.000019	-2.3e-08	6.0e-07
79	.824436	.023478	.152086	.000012	-3.9e-08	6.3e-07
80	.824436	.023478	.152086	6.5e-06	-5.0e-08	6.0e-07
81	.824436	.023478	.152086	1.3e-06	-5.7e-08	5.7e-07
82	.824436	.023478	.152086	-2.5e-06	-6.0e-08	5.1e-07
83	.824436	.023478	.152086	-5.7e-06	-6.0e-08	4.5e-07
84	.824436	.023478	.152086	-7.8e-06	-5.7e-08	3.8e-07
85	.824436	.023478	.152086	-9.3e-06	-5.3e-08	3.1e-07
86	.824436	.023478	.152086	-9.9e-06	-4.7e-08	2.3e-07
87	.824436	.023478	.152086	-.00001	-4.0e-08	1.7e-07
88	.824436	.023478	.152086	-9.8e-06	-3.3e-08	1.1e-07
89	.824436	.023478	.152086	-9.3e-06	-2.6e-08	5.8e-08
90	.824436	.023478	.152086	-8.3e-06	-1.9e-08	1.2e-08
91	.824436	.023478	.152086	-7.2e-06	-1.3e-08	-2.2e-08
92	.824436	.023478	.152086	-6.0e-06	-7.9e-09	-5.1e-08
93	.824436	.023478	.152086	-4.9e-06	-3.3e-09	-6.9e-08
94	.824436	.023478	.152086	-3.7e-06	5.7e-10	-8.3e-08
95	.824436	.023478	.152086	-2.7e-06	3.6e-09	-8.9e-08
96	.824436	.023478	.152086	-1.7e-06	5.9e-09	-9.1e-08
97	.824436	.023478	.152086	-8.5e-07	7.4e-09	-8.8e-08
98	.824436	.023478	.152086	-1.3e-07	8.4e-09	-8.2e-08
99	.824436	.023478	.152086	4.2e-07	8.7e-09	-7.4e-08
100	.824436	.023478	.152086	8.7e-07	8.7e-09	-6.4e-08

(1) irfname = p3r, impulse = garchr, and response = garchr
(2) irfname = p3r, impulse = p3vol, and response = garchr
(3) irfname = p3r, impulse = p3oi, and response = garchr

Granger Causality (CMA Method)

```
. tsset time
        time variable:  time, 1 to 127

. irf set cmar
(file cmar.irf created)
(file cmar.irf now active)

. var garchr cmavol cmaoi, lags(1/4)

Vector autoregression

Sample:       5      127                          No. of obs      =       123
Log likelihood =  814.5507                        AIC             = -12.61058
FPE            =  6.71e-10                        HQIC            = -12.24839
Det(Sigma_ml)  =  3.55e-10                        SBIC            = -11.71891

Equation           Parms      RMSE     R-sq      chi2     P>chi2
```

garchr	13	.001225	0.4633	106.1758	0.0000
cmavol	13	.205039	0.4629	106.0187	0.0000
cmaoi	13	.089736	0.2961	51.74788	0.0000

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
garchr						
garchr						
L1.	.4618128	.0883253	5.23	0.000	.2886984	.6349273
L2.	.1641758	.095624	1.72	0.086	-.0232438	.3515954
L3.	-.0147788	.0933951	-0.16	0.874	-.1978298	.1682723
L4.	.0759585	.0861658	0.88	0.378	-.0929235	.2448404
cmavol						
L1.	.0006823	.000535	1.28	0.202	-.0003662	.0017309
L2.	-.000106	.0005496	-0.19	0.847	-.0011832	.0009712
L3.	-.0006775	.0005352	-1.27	0.206	-.0017265	.0003714
L4.	.0005415	.00048	1.13	0.259	-.0003993	.0014822
cmaoi						
L1.	.001004	.0012217	0.82	0.411	-.0013904	.0033984
L2.	-.0044146	.0012945	-3.41	0.001	-.0069517	-.0018774
L3.	.0016207	.0012944	1.25	0.211	-.0009162	.0041576
L4.	-.0033623	.0013603	-2.47	0.013	-.0060285	-.0006962
_cons	.0007372	.0002274	3.24	0.001	.0002915	.001183
cmavol						
garchr						
L1.	-2.228709	14.78319	-0.15	0.880	-31.20323	26.74581
L2.	17.66916	16.00479	1.10	0.270	-13.69965	49.03796
L3.	-12.97091	15.63173	-0.83	0.407	-43.60854	17.66672
L4.	3.229754	14.42176	0.22	0.823	-25.03637	31.49588
cmavol						
L1.	-.569982	.0895406	-6.37	0.000	-.7454783	-.3944857
L2.	-.4352594	.091988	-4.73	0.000	-.6155525	-.2549663
L3.	-.402937	.0895757	-4.50	0.000	-.5785021	-.227372
L4.	-.038156	.0803388	-0.47	0.635	-.195617	.1193051
cmaoi						
L1.	.7193535	.2044723	3.52	0.000	.3185952	1.120112
L2.	-.0061372	.2166605	-0.03	0.977	-.430784	.4185096
L3.	.8606314	.2166428	3.97	0.000	.4360192	1.285244
L4.	-.3498513	.2276798	-1.54	0.124	-.7960955	.0963929
_cons	-.0399838	.0380643	-1.05	0.294	-.1145885	.0346209
cmaoi						
garchr						
L1.	-12.62009	6.469875	-1.95	0.051	-25.30081	.0606301
L2.	5.419212	7.004507	0.77	0.439	-8.309369	19.14779
L3.	8.769677	6.841239	1.28	0.200	-4.638905	22.17826
L4.	-4.076669	6.311693	-0.65	0.518	-16.44736	8.294022
cmavol						
L1.	-.0063094	.0391875	-0.16	0.872	-.0831155	.0704967
L2.	-.0484954	.0402586	-1.20	0.228	-.1274008	.03041
L3.	-.0354125	.0392029	-0.90	0.366	-.1122486	.0414237
L4.	-.0513326	.0351603	-1.46	0.144	-.1202455	.0175804
cmaoi						
L1.	.1303332	.0894874	1.46	0.145	-.045059	.3057253
L2.	-.4547085	.0948216	-4.80	0.000	-.6405555	-.2688615
L3.	-.053399	.0948139	-0.56	0.573	-.2392308	.1324328
L4.	.0609506	.0996442	0.61	0.541	-.1343485	.2562497
_cons	-.004572	.0166589	-0.27	0.784	-.0372228	.0280788

. vargranger

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
garchr	cmavol	8.7208	4	0.068
garchr	cmaoi	12.895	4	0.012
garchr	ALL	23.446	8	0.003
cmavol	garchr	1.6345	4	0.803
cmavol	cmaoi	24.116	4	0.000
cmavol	ALL	27.613	8	0.001
Equation	Excluded	chi2	df	Prob > chi2
cmaoi	garchr	4.7754	4	0.311

Equation	Excluded	chi2	df	Prob > chi2
cmaoi	cmavol	3.5158	4	0.475
cmaoi	ALL	7.7272	8	0.461

Impulse Response and FEVD (CMA Method)

```
. irf ctable (cmar garchr garchr fevd, noci) (cmar cmavol garchr fevd, noci) (cmar cmaoi garchr fevd, noci)
> (cmar garchr garchr irf, noci) (cmar cmavol garchr irf, noci) (cmar cmaoi garchr irf, noci)
```

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
0	0	0	0	1	0	0
1	1	0	0	.461813	.000682	.001004
2	.984545	.011135	.00432	.363256	-.000186	-.003329
3	.94548	.010541	.043978	.288723	-.000697	-.001082
4	.936173	.018991	.044836	.255937	.000723	-.002522
5	.913341	.025368	.061291	.178665	.000223	-.001454
6	.90879	.025284	.065926	.177345	.000283	-.001271
7	.905348	.025706	.068946	.111515	-.000215	.000466
8	.904756	.026185	.069059	.087097	.000196	-.000897
9	.902672	.02649	.070838	.070925	-.000014	-.00076
10	.90149	.026365	.072145	.080068	.000155	-.000817
11	.899909	.026502	.073589	.048407	-.000055	.000204
12	.899881	.026508	.073611	.034728	.000097	-.00022
13	.899712	.026615	.073673	.024759	-.000031	-.000203
14	.899629	.026618	.073753	.031995	.000062	-.000431
15	.899183	.026631	.074187	.021459	-.000027	.000024
16	.899196	.026635	.07417	.015779	.00005	-.00008
17	.899162	.026665	.074173	.008918	-.000015	-.000021
18	.899162	.026667	.07417	.012085	.000028	-.000184
19	.899078	.026671	.074251	.008779	-.000016	-1.0e-05
20	.899078	.026674	.074247	.007269	.000022	-.000047
21	.89907	.02668	.07425	.003562	-7.3e-06	.000011
22	.899069	.026681	.07425	.004612	.000014	-.000072
23	.899055	.026682	.074262	.003364	-8.6e-06	-5.9e-06
24	.899055	.026683	.074262	.003217	9.7e-06	-.000028
25	.899052	.026684	.074263	.001499	-4.1e-06	9.3e-06
26	.899052	.026685	.074263	.001835	7.1e-06	-.000029
27	.89905	.026685	.074265	.001252	-4.1e-06	-1.2e-06
28	.899049	.026685	.074265	.001376	4.4e-06	-.000015
29	.899049	.026686	.074266	.000629	-2.4e-06	5.3e-06
30	.899049	.026686	.074266	.000756	3.4e-06	-.000012
31	.899048	.026686	.074266	.000461	-1.9e-06	4.8e-07
32	.899048	.026686	.074266	.000579	2.1e-06	-7.3e-06
33	.899048	.026686	.074266	.000258	-1.3e-06	2.7e-06
34	.899048	.026686	.074266	.000319	1.6e-06	-5.0e-06
35	.899048	.026686	.074266	.000169	-9.4e-07	7.3e-07
36	.899048	.026686	.074266	.000242	1.0e-06	-3.5e-06
37	.899048	.026686	.074266	.000104	-6.7e-07	1.4e-06
38	.899048	.026686	.074266	.000137	7.6e-07	-2.2e-06
39	.899048	.026686	.074266	.000061	-4.7e-07	5.8e-07
40	.899048	.026686	.074266	.000101	4.9e-07	-1.7e-06
41	.899048	.026686	.074266	.000041	-3.4e-07	6.7e-07
42	.899048	.026686	.074266	.000059	3.6e-07	-1.0e-06
43	.899048	.026686	.074266	.000022	-2.3e-07	3.8e-07
44	.899048	.026686	.074266	.000042	2.4e-07	-7.8e-07
45	.899048	.026686	.074266	.000015	-1.7e-07	3.3e-07
46	.899048	.026686	.074266	.000026	1.7e-07	-4.7e-07
47	.899048	.026686	.074266	7.5e-06	-1.2e-07	2.2e-07
48	.899048	.026686	.074266	.000018	1.2e-07	-3.6e-07
49	.899048	.026686	.074266	5.5e-06	-8.4e-08	1.6e-07
50	.899048	.026686	.074266	.000011	8.1e-08	-2.2e-07
51	.899048	.026686	.074266	2.5e-06	-5.7e-08	1.2e-07
52	.899048	.026686	.074266	7.5e-06	5.6e-08	-1.7e-07
53	.899048	.026686	.074266	1.8e-06	-4.2e-08	8.2e-08
54	.899048	.026686	.074266	5.0e-06	3.9e-08	-1.1e-07
55	.899048	.026686	.074266	7.9e-07	-2.9e-08	6.2e-08
56	.899048	.026686	.074266	3.2e-06	2.7e-08	-7.8e-08
57	.899048	.026686	.074266	5.4e-07	-2.0e-08	4.2e-08
58	.899048	.026686	.074266	2.2e-06	1.9e-08	-5.1e-08
59	.899048	.026686	.074266	2.0e-07	-1.4e-08	3.2e-08

60	.899048	.026686	.074266	1.4e-06	1.3e-08	-3.7e-08
61	.899048	.026686	.074266	1.2e-07	-1.0e-08	2.1e-08
62	.899048	.026686	.074266	9.8e-07	9.1e-09	-2.5e-08
63	.899048	.026686	.074266	2.7e-08	-7.0e-09	1.6e-08
64	.899048	.026686	.074266	6.3e-07	6.4e-09	-1.7e-08
65	.899048	.026686	.074266	6.3e-10	-4.9e-09	1.1e-08
66	.899048	.026686	.074266	4.3e-07	4.4e-09	-1.2e-08
67	.899048	.026686	.074266	-1.7e-08	-3.5e-09	8.0e-09
68	.899048	.026686	.074266	2.8e-07	3.1e-09	-8.2e-09
69	.899048	.026686	.074266	-2.3e-08	-2.4e-09	5.5e-09
70	.899048	.026686	.074266	1.9e-07	2.2e-09	-5.7e-09
71	.899048	.026686	.074266	-2.1e-08	-1.7e-09	3.9e-09
72	.899048	.026686	.074266	1.3e-07	1.5e-09	-3.9e-09
73	.899048	.026686	.074266	-2.0e-08	-1.2e-09	2.7e-09

	(1)	(2)	(3)	(1)	(2)	(3)
step	fevd	fevd	fevd	irf	irf	irf
74	.899048	.026686	.074266	8.7e-08	1.0e-09	-2.8e-09
75	.899048	.026686	.074266	-1.6e-08	-8.4e-10	2.0e-09
76	.899048	.026686	.074266	5.8e-08	7.3e-10	-1.9e-09
77	.899048	.026686	.074266	-1.3e-08	-5.8e-10	1.4e-09
78	.899048	.026686	.074266	4.0e-08	5.1e-10	-1.3e-09
79	.899048	.026686	.074266	-1.0e-08	-4.1e-10	9.6e-10
80	.899048	.026686	.074266	2.7e-08	3.6e-10	-9.1e-10
81	.899048	.026686	.074266	-7.9e-09	-2.9e-10	6.8e-10
82	.899048	.026686	.074266	1.8e-08	2.5e-10	-6.4e-10
83	.899048	.026686	.074266	-5.8e-09	-2.0e-10	4.8e-10
84	.899048	.026686	.074266	1.2e-08	1.7e-10	-4.4e-10
85	.899048	.026686	.074266	-4.4e-09	-1.4e-10	3.4e-10
86	.899048	.026686	.074266	8.4e-09	1.2e-10	-3.1e-10
87	.899048	.026686	.074266	-3.2e-09	-9.8e-11	2.3e-10
88	.899048	.026686	.074266	5.7e-09	8.4e-11	-2.1e-10
89	.899048	.026686	.074266	-2.4e-09	-6.9e-11	1.7e-10
90	.899048	.026686	.074266	3.9e-09	5.9e-11	-1.5e-10
91	.899048	.026686	.074266	-1.7e-09	-4.8e-11	1.2e-10
92	.899048	.026686	.074266	2.7e-09	4.1e-11	-1.0e-10
93	.899048	.026686	.074266	-1.3e-09	-3.4e-11	8.1e-11
94	.899048	.026686	.074266	1.8e-09	2.9e-11	-7.3e-11
95	.899048	.026686	.074266	-9.1e-10	-2.4e-11	5.7e-11
96	.899048	.026686	.074266	1.3e-09	2.0e-11	-5.1e-11
97	.899048	.026686	.074266	-6.5e-10	-1.6e-11	4.0e-11
98	.899048	.026686	.074266	8.6e-10	1.4e-11	-3.5e-11
99	.899048	.026686	.074266	-4.7e-10	-1.2e-11	2.8e-11
100	.899048	.026686	.074266	5.9e-10	9.8e-12	-2.5e-11

(1) irfname = cmar, impulse = garchr, and response = garchr
(2) irfname = cmar, impulse = cmavol, and response = garchr
(3) irfname = cmar, impulse = cmaoi, and response = garchr

Milled Rice

Granger Causality (FD Method)

```
. tsset time
        time variable:  time, 1 to 120

. irf set fdm
(file fdm.irf created)
(file fdm.irf now active)

. var garchm fdvol fdoi, lags(1/5)

Vector autoregression

Sample:        6      120                         No. of obs      =       115
Log likelihood =  478.6809                        AIC             = -7.490102
FPE            =  1.13e-07                        HQIC            = -7.025064
Det(Sigma_ml)  =  4.87e-08                        SBIC            = -6.344391

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
garchm               16     .004994   0.3765   69.44455   0.0000
fdvol                16     .396152   0.5627   148.0039   0.0000
fdoi                 16      .15315   0.2370   35.72984   0.0019
----------------------------------------------------------------
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
garchm       |
```

```
      garchm |
         L1. |   .6015071   .0969926     6.20   0.000     .4114051    .7916092
         L2. |  -.2259989   .1123941    -2.01   0.044    -.4462873   -.0057105
         L3. |   .0986694   .1165051     0.85   0.397    -.1296764    .3270151
         L4. |   .0427477   .1177078     0.36   0.716    -.1879554    .2734508
         L5. |  -.0079704   .0990377    -0.08   0.936    -.2020807    .1861398
       fdvol |
         L1. |   .0029578   .0011989     2.47   0.014      .000608    .0053075
         L2. |   .0007833   .0010488     0.75   0.455    -.0012722    .0028388
         L3. |  -.0002661   .0009606    -0.28   0.782    -.0021489    .0016168
         L4. |   .0000573   .0009521     0.06   0.952    -.0018087    .0019233
         L5. |   -.001671   .0009541    -1.75   0.080     -.003541    .0001991
        fdoi |
         L1. |  -.0001995   .0029038    -0.07   0.945    -.0058907    .0054918
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
         L2. |  -.0017896   .0029642    -0.60   0.546    -.0075993    .0040201
         L3. |   .0001287   .0028759     0.04   0.964     -.005508    .0057654
         L4. |   -.004657   .0029638    -1.57   0.116    -.0104659    .0011519


             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]

         L5. |   .0034567   .0029767     1.16   0.246    -.0023775    .0092909
       _cons |   .0010793   .0007157     1.51   0.132    -.0003234     .002482
-------------+----------------------------------------------------------------
fdvol        |
      garchm |
         L1. |   4.111851   7.693498     0.53   0.593    -10.96713    19.19083
         L2. |  -12.96071   8.915149    -1.45   0.146    -30.43408    4.512662
         L3. |     1.0064   9.241234     0.11   0.913    -17.10609    19.11889
         L4. |  -23.64914   9.336638    -2.53   0.011    -41.94862    -5.34967
         L5. |   11.46207   7.855712     1.46   0.145    -3.934843    26.85898
       fdvol |
         L1. |  -.3622938   .0950967    -3.81   0.000    -.5486799   -.1759077
         L2. |    .085714   .0831881     1.03   0.303    -.0773317    .2487598
         L3. |  -.0454688   .0761988    -0.60   0.551    -.1948156    .1038781
         L4. |   .3507932   .0755177     4.65   0.000     .2027812    .4988052
         L5. |    .182665   .0756821     2.41   0.016     .0343308    .3309992
        fdoi |
         L1. |    .786835   .2303278     3.42   0.001     .3354009    1.238269
         L2. |  -.4439489   .2351192    -1.89   0.059     -.904774    .0168762
         L3. |   .6367667   .2281195     2.79   0.005     .1896607    1.083873
         L4. |  -.6385815   .2350888    -2.72   0.007    -1.099347   -.1778158
         L5. |  -.0782563   .2361113    -0.33   0.740    -.5410259    .3845134
       _cons |   .1582295   .0567667     2.79   0.005     .0469687    .2694902
-------------+----------------------------------------------------------------
fdoi         |
      garchm |
         L1. |  -4.409868   2.974262    -1.48   0.138    -10.23931    1.419579
         L2. |  -7.119328   3.446546    -2.07   0.039    -13.87443   -.3642227
         L3. |   7.791849   3.572608     2.18   0.029     .7896658    14.79403
         L4. |  -.4143495   3.609491    -0.11   0.909    -7.488821    6.660122
         L5. |  -7.893384   3.036973    -2.60   0.009    -13.84574   -1.941026
       fdvol |
         L1. |  -.0294575   .0367638    -0.80   0.423    -.1015133    .0425983
         L2. |   .0159736   .0321601     0.50   0.619     -.047059    .0790061
         L3. |   .0170748    .029458     0.58   0.562    -.0406619    .0748114
         L4. |   -.055605   .0291947    -1.90   0.057    -.1128256    .0016155
         L5. |  -.0039654   .0292583    -0.14   0.892    -.0613105    .0533798
        fdoi |
         L1. |   .1040251   .0890434     1.17   0.243    -.0704968    .2785469
         L2. |   .0251048   .0908957     0.28   0.782    -.1530476    .2032571
         L3. |  -.0846315   .0881897    -0.96   0.337    -.2574801    .0882171
         L4. |   .0689379    .090884     0.76   0.448    -.1091915    .2470672
         L5. |   -.156481   .0912793    -1.71   0.086    -.3353851    .0224231
       _cons |   .0678421   .0219457     3.09   0.002     .0248293    .1108548
------------------------------------------------------------------------------

. vargranger

   Granger causality Wald tests
  +------------------------------------------------------------------+
  |          Equation           Excluded |   chi2     df Prob > chi2 |
```

garchm	fdvol	7.4866	5	0.187
garchm	fdoi	3.5262	5	0.619
garchm	ALL	8.9019	10	0.541
fdvol	garchm	12.913	5	0.024
fdvol	fdoi	27.755	5	0.000
fdvol	ALL	42.86	10	0.000
fdoi	garchm	25.687	5	0.000
fdoi	fdvol	5.4421	5	0.364
fdoi	ALL	29.776	10	0.001

Impulse Response and FEVD (FD Method)

```
. irf ctable (fdm garchm garchm fevd, noci) (fdm fdvol garchm fevd, noci) (fdm fdoi garchm fevd, noci) (fdm
> garchm garchm irf, noci) (fdm fdvol garchm irf, noci) (fdm fdoi garchm irf, noci)
```

	(1)	(2)	(3)	(1)	(2)	(3)
step	fevd	fevd	fevd	irf	irf	irf
0	0	0	0	1	0	0
1	1	0	0	.601507	.002958	-.000199
2	.969521	.030455	.000024	.148853	.001497	.000397
3	.962615	.03727	.000115	.019755	.000342	-.001077
4	.961711	.037499	.000789	.065691	-.000023	-.003447
5	.955171	.037206	.007622	.020555	-.000357	-.000912
6	.954213	.037694	.008092	.020304	.00022	-5.1e-06
7	.954081	.037832	.008087	.005258	.00008	.000503
8	.953909	.037859	.008231	.005474	.000223	-.000486
9	.953657	.037979	.008364	.038843	-.00022	.001072
10	.952957	.038031	.009012	.020214	.000165	-.000175
11	.952882	.038093	.009025	-.002454	.000021	.000359
12	.952808	.038095	.009098	-.004397	.000129	-.000553
13	.952606	.038123	.009271	.011623	-.000155	.000283
14	.952499	.038185	.009316	-.003309	.000046	-.000403
15	.952407	.038184	.009408	-.004906	-.000044	.000286
16	.952361	.038184	.009454	-.003767	.000079	-.000316
17	.952293	.038196	.009511	.005606	-.000078	.000254
18	.952244	.038208	.009547	.000543	.000034	-.000159
19	.952228	.03821	.009562	.0008	-.000028	.000236
20	.952197	.03821	.009593	-.002275	.000057	-.000201
21	.952167	.038216	.009616	.002514	-.000043	.000148
22	.952151	.03822	.009629	.000128	.00002	-.000133
23	.952141	.03822	.009639	.000189	-.000025	.000128
24	.952131	.038221	.009648	-.002093	.000033	-.00013
25	.95212	.038223	.009657	.001139	-.000026	.000096
26	.952113	.038224	.009663	.000031	.000014	-.000085
27	.952109	.038224	.009667	.000471	-.000017	.000089
28	.952104	.038225	.009671	-.00104	.000021	-.000075
29	.9521	.038226	.009674	.000662	-.000014	.000062
30	.952098	.038226	.009676	-.000062	9.9e-06	-.000056
31	.952096	.038226	.009678	.000402	-.000012	.000055
32	.952094	.038226	.00968	-.000634	.000012	-.000048
33	.952092	.038227	.009681	.000291	-8.8e-06	.000039
34	.952091	.038227	.009682	-.000119	6.7e-06	-.000037
35	.95209	.038227	.009683	.000302	-7.9e-06	.000035
36	.95209	.038227	.009684	-.000356	7.5e-06	-.00003
37	.952089	.038227	.009684	.00017	-5.4e-06	.000025
38	.952089	.038227	.009684	-.000098	4.6e-06	-.000024
39	.952088	.038227	.009685	.00021	-5.1e-06	.000022
40	.952088	.038227	.009685	-.000202	4.6e-06	-.000019
41	.952088	.038227	.009685	.0001	-3.4e-06	.000016
42	.952087	.038227	.009685	-.000086	3.1e-06	-.000015
43	.952087	.038227	.009685	.000134	-3.2e-06	.000014
44	.952087	.038227	.009686	-.000116	2.8e-06	-.000012
45	.952087	.038227	.009686	.000063	-2.2e-06	.000011
46	.952087	.038227	.009686	-.000064	2.1e-06	-9.8e-06
47	.952087	.038227	.009686	.000085	-2.0e-06	8.8e-06
48	.952087	.038227	.009686	-.000066	1.7e-06	-7.5e-06
49	.952087	.038227	.009686	.000042	-1.4e-06	6.8e-06
50	.952087	.038227	.009686	-.000045	1.3e-06	-6.2e-06
51	.952087	.038227	.009686	.000052	-1.3e-06	5.5e-06
52	.952087	.038227	.009686	-.00004	1.1e-06	-4.8e-06
53	.952087	.038227	.009686	.000028	-9.1e-07	4.3e-06
54	.952087	.038227	.009686	-.000031	8.7e-07	-4.0e-06
55	.952087	.038227	.009686	.000032	-8.1e-07	3.5e-06
56	.952087	.038227	.009686	-.000024	6.8e-07	-3.1e-06
57	.952087	.038227	.009686	.000019	-5.9e-07	2.8e-06
58	.952087	.038227	.009686	-.00002	5.6e-07	-2.5e-06
59	.952087	.038227	.009686	.00002	-5.1e-07	2.2e-06
60	.952087	.038227	.009686	-.000015	4.3e-07	-2.0e-06
61	.952087	.038227	.009686	.000013	-3.8e-07	1.8e-06
62	.952087	.038227	.009686	-.000013	3.6e-07	-1.6e-06
63	.952087	.038227	.009686	.000012	-3.2e-07	1.4e-06
64	.952087	.038227	.009686	-9.4e-06	2.7e-07	-1.3e-06

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
65	.952087	.038227	.009686	8.4e-06	-2.5e-07	1.1e-06
66	.952087	.038227	.009686	-8.5e-06	2.3e-07	-1.0e-06
67	.952087	.038227	.009686	7.5e-06	-2.0e-07	9.0e-07
68	.952087	.038227	.009686	-6.0e-06	1.7e-07	-8.0e-07
69	.952087	.038227	.009686	5.5e-06	-1.6e-07	7.2e-07
70	.952087	.038227	.009686	-5.4e-06	1.4e-07	-6.5e-07
71	.952087	.038227	.009686	4.6e-06	-1.3e-07	5.7e-07
72	.952087	.038227	.009686	-3.8e-06	1.1e-07	-5.1e-07
73	.952087	.038227	.009686	3.6e-06	-1.0e-07	4.6e-07
74	.952087	.038227	.009686	-3.4e-06	9.2e-08	-4.1e-07
75	.952087	.038227	.009686	2.9e-06	-8.1e-08	3.7e-07
76	.952087	.038227	.009686	-2.5e-06	7.2e-08	-3.3e-07
77	.952087	.038227	.009686	2.3e-06	-6.5e-08	2.9e-07
78	.952087	.038227	.009686	-2.1e-06	5.8e-08	-2.6e-07
79	.952087	.038227	.009686	1.8e-06	-5.1e-08	2.3e-07
80	.952087	.038227	.009686	-1.6e-06	4.6e-08	-2.1e-07
81	.952087	.038227	.009686	1.5e-06	-4.1e-08	1.9e-07
82	.952087	.038227	.009686	-1.4e-06	3.7e-08	-1.7e-07
83	.952087	.038227	.009686	1.2e-06	-3.3e-08	1.5e-07
84	.952087	.038227	.009686	-1.0e-06	2.9e-08	-1.3e-07
85	.952087	.038227	.009686	9.5e-07	-2.6e-08	1.2e-07
86	.952087	.038227	.009686	-8.5e-07	2.4e-08	-1.1e-07
87	.952087	.038227	.009686	7.4e-07	-2.1e-08	9.5e-08
88	.952087	.038227	.009686	-6.6e-07	1.9e-08	-8.5e-08
89	.952087	.038227	.009686	6.1e-07	-1.7e-08	7.6e-08
90	.952087	.038227	.009686	-5.4e-07	1.5e-08	-6.8e-08
91	.952087	.038227	.009686	4.7e-07	-1.3e-08	6.0e-08
92	.952087	.038227	.009686	-4.2e-07	1.2e-08	-5.4e-08
93	.952087	.038227	.009686	3.9e-07	-1.1e-08	4.8e-08
94	.952087	.038227	.009686	-3.4e-07	9.5e-09	-4.3e-08
95	.952087	.038227	.009686	3.0e-07	-8.5e-09	3.9e-08
96	.952087	.038227	.009686	-2.7e-07	7.6e-09	-3.4e-08
97	.952087	.038227	.009686	2.5e-07	-6.8e-09	3.1e-08
98	.952087	.038227	.009686	-2.2e-07	6.1e-09	-2.7e-08
99	.952087	.038227	.009686	1.9e-07	-5.4e-09	2.5e-08
100	.952087	.038227	.009686	-1.7e-07	4.9e-09	-2.2e-08

(1) irfname = fdm, impulse = garchm, and response = garchm
(2) irfname = fdm, impulse = fdvol, and response = garchm
(3) irfname = fdm, impulse = fdoi, and response = garchm

Granger Causality (P3 Method)

```
. tsset time
        time variable:  time, 1 to 121

. irf set p3m
(file p3m.irf created)
(file p3m.irf now active)

. var garchm p3vol p3oi, lags(1/5)

Vector autoregression

Sample:       6      121                          No. of obs      =       116
Log likelihood =  530.6909                        AIC             = -8.322257
FPE            =  4.90e-08                        HQIC            = -7.859719
Det(Sigma_ml)  =  2.13e-08                        SBIC            =  -7.18284

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
garchm               16      .00477   0.4260   86.0969   0.0000
p3vol                16     .359254   0.4193  83.77463   0.0000
p3oi                 16     .135435   0.8612   719.497   0.0000
----------------------------------------------------------------
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
garchm       |
      garchm |
         L1. |   .5911772    .100337     5.89   0.000     .3945203    .7878341
         L2. |   -.233564   .1139331    -2.05   0.040    -.4568688   -.0102591
         L3. |   .1389206   .1176557     1.18   0.238    -.0916804    .3695216
```

```
         L4. |  -.0046484   .1165485    -0.04   0.968    -.2330791    .2237824
         L5. |   .0273461   .0957494     0.29   0.775    -.1603192    .2150114
       p3vol |
         L1. |   .0003317   .0010109     0.33   0.743    -.0016497     .002313
         L2. |  -.0012912    .000907    -1.42   0.155    -.0030689    .0004865
         L3. |  -.0011858   .0008888    -1.33   0.182    -.0029279    .0005562
         L4. |  -.0010621   .0008692    -1.22   0.222    -.0027657    .0006416
         L5. |  -.0009183   .0008523    -1.08   0.281    -.0025887    .0007521
        p3oi |
         L1. |   .0042469    .003303     1.29   0.199    -.0022268    .0107207
         L2. |  -.0043713   .0050075    -0.87   0.383    -.0141859    .0054433
         L3. |   .0041125    .004901     0.84   0.401    -.0054934    .0137184
         L4. |  -.0062348   .0048285    -1.29   0.197    -.0156985    .0032288
         L5. |   .0082588   .0034289     2.41   0.016     .0015383    .0149793
       _cons |   .0015171   .0005583     2.72   0.007     .0004227    .0026114
-------------+----------------------------------------------------------------
p3vol        |
      garchm |
         L1. |   13.56663   7.556793     1.80   0.073    -1.244409    28.37768
         L2. |  -7.503612   8.580774    -0.87   0.382    -24.32162    9.314395
         L3. |   12.98333   8.861139     1.47   0.143     -4.38418    30.35084
         L4. |  -20.56606   8.777745    -2.34   0.019    -37.77012   -3.361991
                 Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
         L5. |   12.37189   7.211281     1.72   0.086    -1.761956    26.50575
       p3vol |
         L1. |   .1813719   .0761361     2.38   0.017      .032148    .3305959


             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]

         L2. |   .1662555   .0683102     2.43   0.015       .03237     .300141
         L3. |  -.0099347   .0669403    -0.15   0.882    -.1411353    .1212658
         L4. |   .1829413   .0654653     2.79   0.005     .0546317    .3112509
         L5. |  -.0060709   .0641869    -0.09   0.925    -.1318749     .119733
        p3oi |
         L1. |   1.068023   .2487623     4.29   0.000     .5804576    1.555588
         L2. |  -1.120376   .3771378    -2.97   0.003    -1.859552   -.3811995
         L3. |   1.252971   .3691181     3.39   0.001     .5295125    1.976429
         L4. |  -1.528619   .3636529    -4.20   0.000    -2.241366   -.8158724
         L5. |   .6767306   .2582444     2.62   0.009     .1705809     1.18288
       _cons |  -.0179049   .0420512    -0.43   0.670    -.1003237    .0645139
-------------+----------------------------------------------------------------
p3oi         |
      garchm |
         L1. |  -2.134806   2.848826    -0.75   0.454    -7.718403    3.448791
         L2. |   -5.60574   3.234856    -1.73   0.083    -11.94594    .7344606
         L3. |   6.599546    3.34055     1.98   0.048     .0521881     13.1469
         L4. |  -1.287298   3.309112    -0.39   0.697    -7.773038    5.198441
         L5. |  -3.685058   2.718572    -1.36   0.175    -9.013362    1.643245
       p3vol |
         L1. |  -.0383016   .0287024    -1.33   0.182    -.0945573    .0179542
         L2. |   .0004541   .0257522     0.02   0.986    -.0500192    .0509274
         L3. |  -.0044454   .0252357    -0.18   0.860    -.0539066    .0450157
         L4. |  -.0146685   .0246797    -0.59   0.552    -.0630398    .0337028
         L5. |    .014683   .0241977     0.61   0.544    -.0327437    .0621097
        p3oi |
         L1. |   1.067046   .0937806    11.38   0.000     .8832392    1.250852
         L2. |  -.1418135   .1421767    -1.00   0.319    -.4204748    .1368477
         L3. |  -.0798038   .1391534    -0.57   0.566    -.3525394    .1929319
         L4. |   .2061639   .1370931     1.50   0.133    -.0625335    .4748614
         L5. |  -.1574802   .0973552    -1.62   0.106     -.348293    .0333326
       _cons |   .0103994   .0158528     0.66   0.512    -.0206716    .0414703
------------------------------------------------------------------------------

. vargranger

   Granger causality Wald tests
  +------------------------------------------------------------------+
  |          Equation           Excluded |   chi2     df Prob > chi2 |
  |--------------------------------------+---------------------------|
  |            garchm              p3vol |  7.3055     5    0.199    |
  |            garchm               p3oi |  17.858     5    0.003    |
  |            garchm                ALL |  19.679    10    0.032    |
```

p3vol	garchm	8.7342	5	0.120
p3vol	p3oi	44.358	5	0.000
p3vol	ALL	50.517	10	0.000
p3oi	garchm	11.612	5	0.041
p3oi	p3vol	2.3111	5	0.805
p3oi	ALL	16.849	10	0.078

Impulse Response and FEVD (P3 Method)

```
. irf ctable (p3m garchm garchm fevd, noci) (p3m p3vol garchm fevd, noci) (p3m p3oi garchm fevd, noci) (p3m
> garchm garchm irf, noci) (p3m p3vol garchm irf, noci) (p3m p3oi garchm irf, noci)
```

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
0	0	0	0	1	0	0
1	1	0	0	.591177	.000332	.004247
2	.989346	.000433	.010221	.11136	-.001198	.003025
3	.980727	.004017	.015256	.017675	-.002188	.002976
4	.964199	.016059	.019742	.050238	-.002632	-.002387
5	.943578	.034093	.02233	.026893	-.002436	.000465
6	.92965	.048352	.021998	.021779	-.001831	.004368
7	.91377	.054952	.031278	-.036675	-.001468	.005924
8	.89486	.057578	.047562	-.075488	-.001305	.00437

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
9	.885194	.059453	.055353	-.050223	-.001196	.004022
10	.877048	.061138	.061814	-.035825	-.000899	.003574
11	.871176	.061911	.066913	-.056849	-.000622	.003344
12	.866949	.061854	.071198	-.069514	-.000401	.002429
13	.86521	.061571	.073219	-.060226	-.000265	.001558
14	.864686	.061378	.073936	-.047754	-.000111	.000728
15	.864723	.061265	.074012	-.039316	.000034	.000341
16	.864802	.061207	.073991	-.033257	.000161	-.000111
17	.864801	.061235	.073964	-.02559	.000228	-.000523
18	.864615	.061321	.074064	-.015598	.000267	-.000892
19	.864186	.061429	.074384	-.006095	.000285	-.001051
20	.863637	.061539	.074824	.000186	.000292	-.001141
21	.863025	.061641	.075334	.004678	.000276	-.001153
22	.862434	.061718	.075848	.00883	.000245	-.001135
23	.861898	.061761	.076341	.01224	.000206	-.001042
24	.861476	.061776	.076748	.01403	.000165	-.00091
25	.861174	.061772	.077053	.01445	.000123	-.000747
26	.860986	.06176	.077254	.01405	.000082	-.000587
27	.860881	.061745	.077374	.013161	.000043	-.000425
28	.860835	.061731	.077434	.011772	9.5e-06	-.000272
29	.860822	.061722	.077456	.00994	-.000018	-.000129
30	.860823	.061719	.077458	.007867	-.000039	-.00001
31	.860823	.061721	.077456	.005811	-.000055	.000086
32	.860815	.061726	.077458	.003875	-.000064	.000159
33	.860799	.061733	.077468	.002097	-.000069	.00021
34	.860774	.06174	.077485	.000522	-.000068	.00024
35	.860746	.061747	.077508	-.000778	-.000065	.000251
36	.860717	.061751	.077532	-.001775	-.000058	.000246
37	.860691	.061755	.077554	-.002479	-.00005	.000229
38	.86067	.061756	.077574	-.00292	-.00004	.000203
39	.860655	.061756	.077589	-.003123	-.000031	.000171
40	.860644	.061756	.077599	-.003117	-.000021	.000136
41	.860639	.061755	.077606	-.002942	-.000012	.0001
42	.860636	.061755	.077609	-.002642	-4.6e-06	.000066
43	.860635	.061754	.07761	-.002259	2.0e-06	.000035
44	.860635	.061754	.077611	-.001829	7.1e-06	7.5e-06
45	.860635	.061754	.077611	-.001381	.000011	-.000015
46	.860635	.061754	.077611	-.000945	.000013	-.000032
47	.860634	.061755	.077611	-.000542	.000015	-.000044
48	.860633	.061755	.077612	-.000188	.000015	-.000052
49	.860632	.061755	.077613	.000109	.000014	-.000055
50	.86063	.061756	.077614	.000343	.000013	-.000055
51	.860629	.061756	.077615	.000514	.000011	-.000051
52	.860628	.061756	.077616	.000624	9.3e-06	-.000046
53	.860627	.061756	.077617	.00068	7.2e-06	-.000039
54	.860627	.061756	.077617	.000688	5.1e-06	-.000032
55	.860626	.061756	.077618	.000658	3.1e-06	-.000024
56	.860626	.061756	.077618	.000598	1.4e-06	-.000016
57	.860626	.061756	.077618	.000518	-1.4e-07	-9.2e-06
58	.860626	.061756	.077618	.000425	-1.3e-06	-3.0e-06
59	.860626	.061756	.077618	.000327	-2.2e-06	2.1e-06
60	.860626	.061756	.077618	.00023	-2.8e-06	6.2e-06
61	.860626	.061756	.077618	.00014	-3.2e-06	9.1e-06
62	.860626	.061756	.077618	.000059	-3.3e-06	.000011

```
|63      | .860626   | .061756   | .077618   | -9.3e-06  | -3.2e-06  | .000012   |
|64      | .860626   | .061756   | .077618   | -.000064  | -2.9e-06  | .000012   |
|65      | .860626   | .061756   | .077618   | -.000105  | -2.6e-06  | .000012   |
|66      | .860626   | .061756   | .077618   | -.000132  | -2.2e-06  | .00001    |
|67      | .860626   | .061756   | .077618   | -.000147  | -1.7e-06  | 9.0e-06   |
|68      | .860626   | .061756   | .077618   | -.000151  | -1.2e-06  | 7.4e-06   |
|69      | .860626   | .061756   | .077618   | -.000147  | -7.9e-07  | 5.6e-06   |
|70      | .860626   | .061756   | .077618   | -.000135  | -3.9e-07  | 4.0e-06   |
|71      | .860626   | .061756   | .077618   | -.000118  | -4.5e-08  | 2.4e-06   |
|72      | .860626   | .061756   | .077618   | -.000098  | 2.3e-07   | 9.7e-07   |
|73      | .860626   | .061756   | .077618   | -.000077  | 4.5e-07   | -2.2e-07  |
|74      | .860626   | .061756   | .077618   | -.000056  | 6.0e-07   | -1.2e-06  |
|75      | .860626   | .061756   | .077618   | -.000035  | 6.8e-07   | -1.9e-06  |
|76      | .860626   | .061756   | .077618   | -.000017  | 7.2e-07   | -2.3e-06  |
|77      | .860626   | .061756   | .077618   | -1.3e-06  | 7.1e-07   | -2.6e-06  |
|78      | .860626   | .061756   | .077618   | .000011   | 6.6e-07   | -2.7e-06  |
|79      | .860626   | .061756   | .077618   | .000021   | 5.9e-07   | -2.6e-06  |
|80      | .860626   | .061756   | .077618   | .000028   | 5.0e-07   | -2.4e-06  |
|81      | .860626   | .061756   | .077618   | .000032   | 4.0e-07   | -2.1e-06  |
|82      | .860626   | .061756   | .077618   | .000033   | 2.9e-07   | -1.7e-06  |
|83      | .860626   | .061756   | .077618   | .000033   | 2.0e-07   | -1.3e-06  |
|84      | .860626   | .061756   | .077618   | .00003    | 1.1e-07   | -9.6e-07  |
|85      | .860626   | .061756   | .077618   | .000027   | 2.7e-08   | -6.0e-07  |
|86      | .860626   | .061756   | .077618   | .000023   | -3.8e-08  | -2.8e-07  |
|87      | .860626   | .061756   | .077618   | .000018   | -8.8e-08  | -1.1e-08  |
|88      | .860626   | .061756   | .077618   | .000013   | -1.2e-07  | 2.1e-07   |
|89      | .860626   | .061756   | .077618   | 8.8e-06   | -1.5e-07  | 3.8e-07   |
|90      | .860626   | .061756   | .077618   | 4.7e-06   | -1.6e-07  | 4.9e-07   |
|91      | .860626   | .061756   | .077618   | 1.1e-06   | -1.6e-07  | 5.6e-07   |
|92      | .860626   | .061756   | .077618   | -1.9e-06  | -1.5e-07  | 5.8e-07   |
|93      | .860626   | .061756   | .077618   | -4.2e-06  | -1.3e-07  | 5.7e-07   |
|94      | .860626   | .061756   | .077618   | -5.8e-06  | -1.1e-07  | 5.3e-07   |
|95      | .860626   | .061756   | .077618   | -6.8e-06  | -9.2e-08  | 4.7e-07   |
|96      | .860626   | .061756   | .077618   | -7.2e-06  | -7.0e-08  | 3.9e-07   |
|97      | .860626   | .061756   | .077618   | -7.2e-06  | -4.8e-08  | 3.1e-07   |
|98      | .860626   | .061756   | .077618   | -6.8e-06  | -2.8e-08  | 2.3e-07   |
|99      | .860626   | .061756   | .077618   | -6.1e-06  | -9.8e-09  | 1.5e-07   |
|100     | .860626   | .061756   | .077618   | -5.2e-06  | 5.2e-09   | 7.8e-08   |
+--------------------------------------------------------------------------------+
(1) irfname = p3m, impulse = garchm, and response = garchm
(2) irfname = p3m, impulse = p3vol, and response = garchm
(3) irfname = p3m, impulse = p3oi, and response = garchm
```

Granger Causality (CMA Method)

```
. tsset time
        time variable:  time, 1 to 119

. irf set cmam
(file cmam.irf created)
(file cmam.irf now active)

. var garchm cmavol cmaoi, lags(1/3)

Vector autoregression

Sample:       4      119                         No. of obs      =       116
Log likelihood =  612.0589                       AIC             =  -10.0355
FPE            =  8.81e-09                       HQIC            = -9.746413
Det(Sigma_ml)  =  5.24e-09                       SBIC            = -9.323364

Equation           Parms      RMSE     R-sq      chi2     P>chi2
----------------------------------------------------------------
garchm               10     .004676   0.4154   82.42696   0.0000
cmavol               10     .207052   0.4518   95.58593   0.0000
cmaoi                10     .087607   0.3007    49.8698   0.0000
----------------------------------------------------------------
------------------------------------------------------------------------------
             |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
garchm       |
      garchm |
         L1. |   .6557957    .092877     7.06   0.000     .4737603    .8378312
         L2. |  -.1636187    .109394    -1.50   0.135     -.378027    .0507896
         L3. |   .1089096   .0922027     1.18   0.238    -.0718043    .2896236
      cmavol |
         L1. |  -.0047655   .0017956    -2.65   0.008    -.0082847   -.0012462
         L2. |  -.0064984   .0019412    -3.35   0.001    -.0103031   -.0026938
         L3. |  -.0036996   .0016987    -2.18   0.029     -.007029   -.0003702
       cmaoi |
         L1. |    .008841   .0048596     1.82   0.069    -.0006836    .0183656
         L2. |   .0007178   .0044381     0.16   0.872    -.0079807    .0094163
         L3. |   .0055065   .0048803     1.13   0.259    -.0040586    .0150716
       _cons |   .0009786    .000497     1.97   0.049     4.45e-06    .0019528
-------------+----------------------------------------------------------------
```

	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
cmavol						
garchm						
L1.	3.201407	4.112778	0.78	0.436	-4.85949	11.2623
L2.	1.952684	4.844187	0.40	0.687	-7.541747	11.44712
L3.	1.246162	4.08292	0.31	0.760	-6.756214	9.248537
cmavol						
L1.	-.6280672	.0795119	-7.90	0.000	-.7839076	-.4722268
L2.	-.4631388	.0859593	-5.39	0.000	-.6316159	-.2946618
L3.	-.4243152	.0752212	-5.64	0.000	-.571746	-.2768844
cmaoi						
L1.	.7433044	.2151925	3.45	0.001	.3215349	1.165074
L2.	.244413	.1965277	1.24	0.214	-.1407743	.6296003
L3.	.7969228	.2161073	3.69	0.000	.3733603	1.220485
_cons	-.0387496	.0220099	-1.76	0.078	-.0818883	.004389
cmaoi						
garchm						
L1.	1.88354	1.740184	1.08	0.279	-1.527158	5.294238
L2.	-6.895753	2.049655	-3.36	0.001	-10.913	-2.878504
L3.	3.893586	1.72755	2.25	0.024	.5076492	7.279522
cmavol						
L1.	.0006	.0336428	0.02	0.986	-.0653387	.0665386
L2.	.0170802	.0363708	0.47	0.639	-.0542052	.0883656
L3.	.0215352	.0318273	0.68	0.499	-.0408452	.0839156
cmaoi						
L1.	.147642	.0910515	1.62	0.105	-.0308156	.3260996
	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
L2.	-.4242101	.0831541	-5.10	0.000	-.5871891	-.261231
L3.	.0067385	.0914385	0.07	0.941	-.1724777	.1859548
_cons	-.008012	.0093128	-0.86	0.390	-.0262646	.0102407

```
. vargranger
```

Granger causality Wald tests

Equation	Excluded	chi2	df	Prob > chi2
garchm	cmavol	13.418	3	0.004
garchm	cmaoi	3.6074	3	0.307
garchm	ALL	17.423	6	0.008
cmavol	garchm	2.4016	3	0.493
cmavol	cmaoi	21.101	3	0.000
cmavol	ALL	25.187	6	0.000
cmaoi	garchm	12.257	3	0.007
cmaoi	cmavol	.54747	3	0.908
cmaoi	ALL	13.089	6	0.042

Impulse Response and FEVD (CMA Method)

```
. irf ctable (cmam garchm garchm fevd, noci) (cmam cmavol garchm fevd, noci) (cmam cmaoi garchm fevd, noci)
> (cmam garchm garchm irf, noci) (cmam cmavol garchm irf, noci) (cmam cmaoi garchm irf, noci)
```

step	(1) fevd	(2) fevd	(3) fevd	(1) irf	(2) irf	(3) irf
0	0	0	0	1	0	0
1	1	0	0	.655796	-.004765	.008841
2	.953134	.02848	.018386	.267846	-.006625	.004279
3	.902067	.077195	.020737	.09384	-.002716	-.000863
4	.894453	.084897	.020651	.06486	.002445	-.004686
5	.884734	.090321	.024944	.064405	.000698	-.002307
6	.883578	.090473	.025949	.070075	-.001594	.001726
7	.880782	.092798	.02642	.042706	-.001491	.003159
8	.876924	.094739	.028337	.001602	.000463	-.000441
9	.876681	.094951	.028368	-.017616	.000623	-.002253
10	.875423	.09521	.029367	.004971	1.9e-06	-.000656
11	.875347	.095201	.029453	.020703	-.00045	.001419
12	.874824	.095335	.029841	.00861	-.000107	.000725
13	.874725	.095331	.029944	-.009394	.000091	-.000569
14	.874667	.095327	.030006	-.006337	.000138	-.000661
15	.874574	.095334	.030092	.004306	-.000019	.000173
16	.87457	.095333	.030098	.005832	-.000059	.000377
17	.874544	.095331	.030125	-.00068	-.000056	.000059
18	.87454	.095334	.030126	-.003064	.00003	-.000199
19	.874533	.095333	.030134	-.000666	.000039	-.000086
20	.87453	.095335	.030135	.001544	9.1e-06	.000052
21	.87453	.095335	.030135	.000844	-.000034	.000079

22	.874528	.095336	.030137	-.000355	-.000012	2.0e-06
23	.874528	.095336	.030137	-.000637	.000012	-.000037
24	.874527	.095336	.030137	-.000069	.000016	-.000028
25	.874527	.095336	.030137	.000291	-5.6e-06	.000014
26	.874527	.095336	.030137	.000236	-9.0e-06	.000022
27	.874527	.095336	.030137	-.000083	-1.7e-06	3.8e-06
28	.874527	.095336	.030137	-.000182	6.1e-06	-.000016
29	.874527	.095336	.030137	-.000045	1.9e-06	-7.2e-06
30	.874527	.095336	.030137	.000116	-1.7e-06	6.1e-06
31	.874527	.095336	.030137	.00007	-2.4e-06	7.9e-06
32	.874527	.095336	.030137	-.000042	5.5e-07	-1.7e-06
33	.874527	.095336	.030137	-.000065	1.1e-06	-4.8e-06
34	.874527	.095336	.030137	6.8e-06	5.4e-07	-1.1e-06
35	.874527	.095336	.030137	.000039	-6.5e-07	2.7e-06
36	.874527	.095336	.030137	.000012	-4.2e-07	1.3e-06
37	.874527	.095336	.030137	-.00002	1.7e-08	-8.3e-07
38	.874527	.095336	.030137	-.000013	4.1e-07	-1.2e-06
39	.874527	.095336	.030137	5.7e-06	7.3e-08	9.8e-08
40	.874527	.095336	.030137	.00001	-1.5e-07	6.3e-07
41	.874527	.095336	.030137	2.0e-07	-1.8e-07	3.0e-07
42	.874527	.095336	.030137	-5.1e-06	7.5e-08	-2.9e-07
43	.874527	.095336	.030137	-2.7e-06	1.0e-07	-2.6e-07
44	.874527	.095336	.030137	2.0e-06	2.2e-08	1.5e-08
45	.874527	.095336	.030137	2.3e-06	-7.7e-08	2.0e-07
46	.874527	.095336	.030137	5.0e-08	-2.5e-08	5.8e-08
47	.874527	.095336	.030137	-1.5e-06	2.3e-08	-8.3e-08
48	.874527	.095336	.030137	-6.2e-07	3.4e-08	-8.7e-08
49	.874527	.095336	.030137	6.1e-07	-8.7e-09	2.7e-08
50	.874527	.095336	.030137	7.3e-07	-1.6e-08	5.7e-08
51	.874527	.095336	.030137	-1.4e-07	-6.5e-09	1.2e-08

	(1)	(2)	(3)	(1)	(2)	(3)
step	fevd	fevd	fevd	irf	irf	irf
52	.874527	.095336	.030137	-4.7e-07	1.1e-08	-3.5e-08
53	.874527	.095336	.030137	-1.3e-07	5.1e-09	-1.7e-08
54	.874527	.095336	.030137	2.6e-07	-1.5e-09	1.1e-08
55	.874527	.095336	.030137	1.6e-07	-5.6e-09	1.7e-08
56	.874527	.095336	.030137	-7.9e-08	-1.0e-10	-2.1e-09
57	.874527	.095336	.030137	-1.4e-07	2.2e-09	-9.2e-09
58	.874527	.095336	.030137	2.2e-09	1.9e-09	-3.6e-09
59	.874527	.095336	.030137	7.4e-08	-1.2e-09	4.7e-09
60	.874527	.095336	.030137	3.4e-08	-1.2e-09	3.4e-09
61	.874527	.095336	.030137	-3.4e-08	-1.7e-10	-7.8e-10
62	.874527	.095336	.030137	-3.0e-08	9.9e-10	-2.8e-09
63	.874527	.095336	.030137	4.1e-09	2.5e-10	-4.0e-10
64	.874527	.095336	.030137	2.2e-08	-3.1e-10	1.2e-09
65	.874527	.095336	.030137	5.4e-09	-4.3e-10	9.8e-10
66	.874527	.095336	.030137	-9.4e-09	1.4e-10	-4.9e-10
67	.874527	.095336	.030137	-8.4e-09	2.2e-10	-6.9e-10
68	.874527	.095336	.030137	2.9e-09	7.7e-11	-8.8e-11
69	.874527	.095336	.030137	5.8e-09	-1.5e-10	4.6e-10
70	.874527	.095336	.030137	1.1e-09	-6.3e-11	1.9e-10
71	.874527	.095336	.030137	-3.5e-09	3.0e-11	-1.6e-10
72	.874527	.095336	.030137	-1.8e-09	7.6e-11	-2.1e-10
73	.874527	.095336	.030137	1.2e-09	-6.5e-12	4.0e-11
74	.874527	.095336	.030137	1.7e-09	-3.2e-11	1.2e-10
75	.874527	.095336	.030137	-1.3e-10	-2.2e-11	4.2e-11
76	.874527	.095336	.030137	-1.0e-09	1.9e-11	-6.8e-11
77	.874527	.095336	.030137	-4.0e-10	1.4e-11	-4.2e-11
78	.874527	.095336	.030137	4.9e-10	2.8e-13	1.5e-11
79	.874527	.095336	.030137	3.9e-10	-1.3e-11	3.7e-11
80	.874527	.095336	.030137	-9.5e-11	-2.0e-12	1.7e-12
81	.874527	.095336	.030137	-3.0e-10	4.3e-12	-1.8e-11
82	.874527	.095336	.030137	-4.4e-11	5.2e-12	-1.1e-11
83	.874527	.095336	.030137	1.4e-10	-2.2e-12	8.1e-12
84	.874527	.095336	.030137	1.0e-10	-2.7e-12	8.6e-12
85	.874527	.095336	.030137	-5.3e-11	-8.2e-13	1.0e-13
86	.874527	.095336	.030137	-7.4e-11	2.1e-12	-6.2e-12
87	.874527	.095336	.030137	-6.2e-12	7.2e-13	-1.8e-12
88	.874527	.095336	.030137	4.7e-11	-4.8e-13	2.4e-12
89	.874527	.095336	.030137	2.0e-11	-1.0e-12	2.6e-12
90	.874527	.095336	.030137	-1.7e-11	1.7e-13	-7.4e-13
91	.874527	.095336	.030137	-2.2e-11	4.4e-13	-1.6e-12
92	.874527	.095336	.030137	3.6e-12	2.6e-13	-4.3e-13
93	.874527	.095336	.030137	1.3e-11	-2.9e-13	9.5e-13
94	.874527	.095336	.030137	4.3e-12	-1.7e-13	5.0e-13
95	.874527	.095336	.030137	-7.0e-12	2.0e-14	-2.6e-13
96	.874527	.095336	.030137	-4.7e-12	1.7e-13	-4.9e-13
97	.874527	.095336	.030137	1.7e-12	1.0e-14	1.8e-14
98	.874527	.095336	.030137	4.0e-12	-6.1e-14	2.5e-13
99	.874527	.095336	.030137	2.7e-13	-6.3e-14	1.3e-13
100	.874527	.095336	.030137	-2.0e-12	3.5e-14	-1.2e-13

(1) irfname = cmam, impulse = garchm, and response = garchm
(2) irfname = cmam, impulse = cmavol, and response = garchm
(3) irfname = cmam, impulse = cmaoi, and response = garchm