Three Essays on Aggregate and Disaggregate Price Risk Measurement and Explanation for Chinese Major Grains

by

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CONTENTS

ABSTRACT

This dissertation consists of three essays. In the first essay, econometric models are used to measure price risk in a study for major grains (wheat, rice, corn, and soybeans) in China. Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models and Multiplicative Heteroskedasticity (M Het) models are applied to estimate time-varying price variance, and then covariances are estimated by a simple two-step process assuming constant conditional correlations. An aggregate price risk index is constructed from these variances and covariances using an economic index number approach. In theory, this approach is superior to the more common approach of estimating a univariate GARCH model for an aggregate price index. This easay compares the two approaches to measuring aggregate price risk and finds low correlations. Thus there is substantial difference between the two approaches in practice as well as in theory.

The previous essay measures aggregate price risk but does not explain price risk. The second essay attempts to investigate potential factors that contribute to aggregate price risk of major grain products (rice, wheat, corn and soybeans) on monthly base in China from mid 1980s to recent year from both theoretical and empirical perspectives. The superlative price risk indexes are explained by a set of key variables that characterize China's economy, agricultural market and trade as well as biological system of major grain in China. These variables account for much of the variation in the aggregate price risk index. Moreover empirical results favor use of the superlative index of aggregate risk rather than standard measures of aggregate risk.

The third essay is an extension of previous two essays by explaining price risk at disaggregate level. Price variances and covariances are modeled using both

Ordinary Least Squares (OLS) and Seemly Unrelated Regression (SUR) techniques. Results are broadly consistent with the previous essays.

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CHAPTER ONE: GENERAL INTRODUCTION

It is well known that farmers in developing countries almost uniformly farm a wide variety of agricultural products including crops and livestock to spread out their family labor and farm resources. Similarly Chinese farmers produce a number of agricultural products to diversify their revenue. Primary grains are rice, wheat, corn, and soybeans over the years, according to Ministry of Agriculture of the People's Republic of China. The subject of price volatility for major grains in China has received increased attention recently for risk management strategies and policy implementations. Major grain (rice, wheat, corn, and soybeans) production, consumption, and trade account for a significant share of China's food system. Grain price variation has large effects on producers, consumers and other market participants. Several studies have estimated price volatility for individual grains in China (Du and Wang 2004; Liu and Wang 2006; Zou et al. 2007), but there are no studies measuring aggregate price risk. This is the first study to analyze price risk for major Chinese grains from an aggregate view point. It evaluates and compares alternative econometric approaches to measuring price variances and covariances. Then it applies economic index number theory to aggregate price risk over the four commodities. This measure of aggregate risk is compared with a more common measure from a univariate Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model of aggregate price, and empirical differences are substantial.

The focus on these four crops is of great importance for the following reasons. Firstly, grain production is the major agricultural industry in China. At the aggregate level, these four major crops jointly account for over 90 per cent of China's grain supply in recent years (Zhou and Tian 2005). Secondly, grain production is major income source for many rural families. These four grains contribute about 60% of the yearly average net income for China's farmers according to statistics from China National Statistical Yearbook (2012). Thirdly, they are crucial to international grain market and have attracted attention worldwide. China is the world's largest producer of rice, the world's biggest consumer of wheat, the world's largest importer of soybeans, and a major exporter of corn in most years.

It is also rational to analyze aggregate level price risk for grain portfolio. It is well accepted that financial volatilities move together over time and across assets. This study focuses on rice, wheat, corn, and soybeans since those crops are partly substitutable in both production and consumption in China. All four crops are widely produced in most provinces in China and have similar planting, growing, and harvesting seasons. Furthermore, the markets for the main Chinese grain crops (rice, wheat, corn, and soybeans) operate in a similar way and are subject to similar grain policies, reforms, and similar degree of government intervention over years (see Wu and McErlean 2003). Over the past decades, prices of major grain peaked together in 1988, mid of 1990, mid of 2000 (see Figure 2.1).

Since 1978 when market oriented reforms and the opening door policy to international trade were implemented, China has gradually adopted various policies to promote free trade of agricultural products. Among those policies, some were known as retrenchment, some as acceleration and others as ambiguity. Moreover, China's rapid economic growth and gradual transition towards a market economy have changed domestic production and consumption patterns and trade behavior significantly in agricultural industry. Consequently prices of agricultural products, especially grains, have fluctuated throughout the last three decades. Farmers make production decisions by responding to both level and volatility of prices. Price uncertainty will lead farmers to be cautious in applying costly inputs and this will tend to decrease output. Rozelle and Huang (1998) indicated that China's farmers could increase (decrease) output as they face less (more) price risk and uncertainty.

It is, therefore, important to understand the grain price volatility and investigate the potential factors contributing to grain price risk in China. However, studies on China's major grain price risk are limited, particularly with regard to farm level grain prices. Some existing studies discuss agricultural commodity price in China more from policy regulatory and marketing development and reform perspectives (Huang and Rozelle 2006; Brauw 2004). Relatively little is written about the quantitative impacts of economic factors and agricultural and trade policy changes on price risk of major agricultural commodities. Some quantitative studies attempt to analyze price volatility for individual grain in China in recent year. Du and Wang (2004) apply time series models to describe price behavior of China's wheat using wheat futures data. No studies analyze price risk for China's major grains portfolio by considering the tight relationship in production and consumption among a group of grains.

This paper is the first effort to explore key factors that may affect price volatility for China's key grains portfolio including rice, wheat, corn and soybeans from both theoretical and empirical perspectives. It is also rational to analyze price risk for a group of grains since those crops are partly substitutable in both production and consumption. The crop production distribution map (see Figure 3.1) shows all four crops are widely produced in most of provinces in China. The crop calendar for these four grains illustrated in Figure 3.2 shows similar planting, growing, and harvesting season across crops. Over the past decades, prices of major grains peaked together in 1988, mid of 1990, mid of 2000 (see Figure 3.1 in Chapter 2). The special features of the Chinese economy and complex reform strategies make the task of explaining price risk important and challenging. The dual price system in China contributes to the complexity of the study. Since the early 1980s, Chinese farmers have faced two prices: the government procurement prices (quota prices and negotiated prices) and market prices. This paper focuses on market prices since the risk portion from market factors continues increasing as the scope of government planning reduces over time. The impact of China's WTO accession in 2001 on price risk is worthy of assessment. After that Chinese government started to rely more on market forces in agricultural products distribution. More wheat, corn, rice, soybeans, cotton and oil seeds are imported due to their higher prices on the domestic market. Chinese farmers face strong competition from cheap imported agriculture products after 2001, especially the significant impact of cheap grain products from abroad. This makes them more vulnerable to economic uncertainty and risk.

There is a huge literature using GARCH models to measure risk, including econometric studies of risk in stock market returns and in agricultural product prices. Part of the attraction of ARCH and GARCH models is that measurement is based on a model of persistent patterns of risk over time rather than on a model explaining risk. In contrast, earlier models of heteroskedasticity generally required an explanation of heteroskedasticity, and such explanations are viewed as tenuous at best.

However there is almost no literature attempting to explain risk as measured by GARCH models. The one exception is in the area of stock market returns. Explanation of return volatility in terms of market fundamentals has been viewed as the most important remaining research issue in econometrics of stock market risk. Early attempts were unsuccessful (Schwert 1989), but there is a small recent literature reporting some progress (Diebold and Yilmaz 2007; Engle and Rangel 2008; Engle, Ghysels and Sohn 2008; Lettau and Ludviqson 2010). Apparently there are no other attempts to explain GARCH measures of price risk reported in the literature.

So this is the first study attempting to explain GARCH measures of price risk, aside from several studies of stock market volatility. Moreover this study uses a theoretically correct application of index number theory to construct measures of aggregate price risk. In contrast, in published studies, stock market volatility was estimated simply from e.g. a univariate GARCH model of aggregate returns.

This study attempts to explicitly measure and explain the impact of key elements on price risk for major grains in China, which is measured using superlative price risk index approach as presented in Chapter 2 of this thesis. Our exploration is motivated by the economic demand and supply theory, which suggests that the volatility of exogenous variables in the demand and supply system should be related to market volatility.

Moreover, in this study, models explaining risk that use the theoretically correct measure of aggregate price risk have a better fit than do models using common measures of aggregate price risk. Given the scale of these four core grains' contribution to China's agricultural economy, it is also important to examine and understand price volatility at the disaggregate level by analyzing individual price variances and covariances. It is well known that the mean level of grain price is responsive to changes in variables such as government policies, income, and input cost that shift demand and supply curves in the market. However, what is not known is how those variables influence price risk, at either an aggregate level or disaggregate level. Do key factors that have significant influences on aggregate price volatility also have similar effects at the disaggregate level? Does the impact of marketing factors such as marketing evolution and grain policies on price volatility vary by grain product? What does the seasonal pattern of individual crop price volatility look like? However, little quantitative information is available publicly. This is the first study of these matters.

Most studies of commodity prices have estimated single-equation models (for example, Mastrangelo 2007; Du and Wang 2004). When the single-equation framework is adapted in this study, several equations are estimated separately by (for example) Ordinary Least Squares (OLS) assuming independence among grain price variances and covariances. However, this assumption seems unrealistic, as prices are influenced by common variables on both production and consumption sides. Hence, it is rational to expect that those individual equations are interrelated and the single-equation framework is less efficient than a system approach such as Seemly Unrelated Regression (SUR) (Zellner 1962; Dwivedi and Srivastava 1978).

A large amount of literature exists on the application of SUR models in agriculture (for example, Miller 1979; Reed and Riggins 1981; Streeter and Tomek 1992; and Barnes and Shields 1998). However, apparently SUR has not been used to model price risk for multiple commodities. Here equations explaining all price variances and covariances are estimated jointly by SUR. Common factors likely to influence price variances and covariances include weather, marketing shocks, and agricultural policies. These may induce correlations between the equations' error terms. This study is the first attempt to quantitatively explore price volatility systematically for core grains in China.

CHAPTER TWO: MEASURING AGGREGATE PRODUCER PRICE RISK FOR MAJOR CHINESE GRAINS

Abstract

Econometric models are used to measure price risk in a study for major grains (wheat, rice, corn, and soybeans) in China. Generalized Autoregressive Conditional Heteroskedasticity (GARCH) models and Multiplicative Heteroskedasticity (M Het) models are applied to estimate time-varying price variance, and then covariances are estimated by a simple two-step process assuming constant conditional correlations. An aggregate price risk index is constructed from these variances and covariances using an economic index number approach. In theory, this approach is superior to the more common approach of estimating a univariate GARCH model for an aggregate price index. This chapter compares the two approaches to measuring aggregate price risk and finds low correlations. Thus there are substantial differences between the two approaches in practice as well as in theory.

Keywords: Aggregate Price Risk, Economic Approach to Index Numbers, Chinese Major Grains

2.1 Introduction

It is well known that farmers in developing countries almost uniformly farm a wide variety of agricultural products including crops and livestock to spread out their family labor and farm resources. Similarly Chinese farmers produce a number of agricultural products to diversify their revenue. Primary grains are rice, wheat, corn, and soybeans over the years, according to Ministry of Agriculture of the People's Republic of China.

This paragraph gives a brief summary of current theoretical understanding of the origin of agricultural price fluctuation. Although price volatility in the agricultural market has not been fully explored, there are two main types of theory proposed. One type of theory is called exogenous (e.g. Deaton and Laroque 1996, 1992), which explains the presence of price variations as the result of external shocks in supply such as weather. In the exogenous theory context, the storage model tends to dominate: marketing speculators sell or store commodities based on their rational expectations of future price changes. When there is no incentive to store, price dynamics simply follow the path of supply shocks. Beck (1993) showed ARCH effects in storable commodity prices (e.g. crops) after investigating prices of various agricultural commodities. The other type of theory is called endogenous (e.g. Chavas and Holt 1993), which explains price movements as the result of market participants' naïve expectations and a time lag between planting and harvest. The Cobweb model is always used: agents make production decisions based on their expectation on market prices; when producers expect high prices to continue, they produce too much and therefore end up with low prices, and vice versa. In both theories, the inelastic demand on staple goods could magnify price fluctuation given that supply cannot adjust quickly in the short run. In practice, price volatility in agricultural markets is driven by market fundamentals as well as government interventions.

Several studies have estimated price volatility for individual grains in China (Du and Wang 2004; Liu and Wang 2006; Zou et al. 2007), but there are no studies measuring aggregate price risk. This is the first study to analyze price risk for major Chinese grains from an aggregate view point. It evaluates and compares alternative econometric approaches to measuring price variances and covariances. Then it applies economic index number theory to aggregate price risk over the four commodities.

This measure of aggregate risk is compared with a more common measure from a univariate Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model of aggregate price, and empirical differences are substantial.

The focus on these four crops is of great importance for the following reasons. Firstly, grain production is the major agricultural industry in China. At the aggregate level, these four major crops account for about 91% of total grain product of China in recent years (Zhou and Tian 2005). Secondly, grain production is major income source for many rural families. These four grains contribute about 60% of the yearly average net income for China's farmers according to statistics from China National Statistical Yearbook (2012). Thirdly, they are crucial to international grain market and have attracted attention worldwide. China is the world's largest producer of rice, the world's biggest consumer of wheat, the world's largest importer of soybeans, and a major exporter of corn in most years.

It is also rational to analyze aggregate level price risk for grain portfolio. It is well accepted that financial volatilities move together over time and across assets. This study focuses on rice, wheat, corn, and soybeans since those crops are partly substitutable in both production and consumption in China. All four crops are widely produced in most provinces in China and have similar planting, growing, and harvesting seasons. Furthermore, the markets for the main Chinese grain crops (rice, wheat, corn, and soybeans) operate in a similar way and are subject to similar grain policies, reforms, and similar degree of government intervention over years (see Wu and McErlean 2003). Over the past decades, prices of major grain peaked together in 1988, mid of 1990, mid of 2000 (see Figure 2.1).

2.2 Literature Review

Farm-level revenue risk reflects risk in both production and price. As in most studies we focus on price risk (farm level yield risk is underestimated by industry level data as is well known). In most previous literature, aggregate price risk over commodities is simply measured as variance of an aggregate price index over commodities (e.g. Chen et al. 1986; Park and Switzer 1995; Flannery and Protopapadakis 2002; Laws and Thompson 2005). Within this simple framework popular approaches for quantifying variance of price index include univariate GARCH models and traditional naïve expectation-based methods. The advantage of this approach is computational simplicity. However these simple approaches involve substantial errors in aggregation over commodities (see the next paragraph on how we will deal with this problem). First, it is well known that aggregation over commodities generally leads to a loss of information and incorrect specification of econometric models (e.g. Kelejian 1980; Pesaran, Pierce, and Kumar 1989; Van Garderen, Lee, and Pesaran 2000). Second and more specifically to measurement of aggregate risk, there is a small literature on contemporaneous aggregation of GARCH models. Nijman and Sentana (1996) considered a simple case of the sum of two independent univariate GARCH(1,1) processes. Aggregation leads to a substantially more complex parametric structure (a “weak” GARCH(2,2) rather than a strong GARCH(1,1)), and standard techniques lead to inconsistent estimators of the aggregate process. This partly reflects misspecification of aggregate conditional variance (Komunjer 2001).

In order to estimate aggregate risk while avoiding the errors in aggregation mentioned above, we proceed in two steps. First, we estimate a multivariate GARCH (or multiplicative Heteroskedasticity) model for individual crop prices, and calculate variances and covariances for these prices. Second, we combine these variances and covariances into an index of aggregate price risk. Recently standard economic theory of index numbers has been extended from aggregation of prices under certainty or risk neutrality into the aggregation of price risk over commodities in production (Coyle 2007). Price variances and covariances are aggregated into an index to measure overall price risk for multiple commodities. This paper applies this superlative index approach to price of major grains in China for the period of 1987 to 2007. The high correlations between grain market prices as well as patterns in price movements over the last 30 years in China indicate that it is important to integrate price covariances into the aggregation of price risk analysis in the study. This study will be the first application of this index number approach to China (Coyle (2007) includes an application to Manitoba crops).

There have been numerous methodologies developed to estimate price risk for a single commodity. This paper applies the widely-used GARCH model， Multiplicative Heteroskedasticity model, and traditional naive expectation-based models. It is well known that ARCH/GARCH models have been frequently applied in the analysis of asset price risk in financial econometric models (e.g. Bollerslev et al. 1988; Bollerslev et al. 1992). Similarly in many respects, these time series models have been widely adopted to successfully measure price risk of agricultural commodities. Holt and Aradhyula (1990) use a GARCH model to estimate price risk for U.S. broiler. Holt and Moschini (2001) apply GARCH to U.S. sow farrow. Du and Wang (2004) use GARCH models to study price behavior in China’s wheat futures market. However little work has been done using ARCH/GARCH to measure price risk of other agricultural commodities in China. This paper also assesses price risk by using Multiplicative Heteroskedasticity (M Het) model, which is well accepted in econometric analysis of risk in agricultural industry after Harvey’s contribution in

1976 (e.g. Dixon et al.1994; Goodwin et al. 2000). Price risk measurement based on Naïve expectation is evaluated in this study as well. Brorsen et al. (1987) apply Naïve expectation on rice farmers' income risk analysis. Chavas and Holt (1990) use this approach to measure first two moments of price for U.S. soy and corn.

This paper estimates price risk over Chinese major grains using alternative hetoroskedasticity methodologies. This study adopts a simple two-step process to estimate price variances and covariances assuming constant conditional correlation as in Bollerslev (1990). This two-step process was suggested by Engle and Sheppard (2001), and revisited by Engle (2002). Price variances are estimated by a standard heteroskedastic method for each commodity, and then price covariance is calculated using correlations and standardized residuals estimated from the first step, assuming constant conditional correlation.

2.3 Methodology

2.3.1 Measuring Price Risk for Individual Commodities

This study assesses the first and second moment of individual commodity price first. Following Bollerslev (1990), Engle and Sheppard (2001), and Engle (2002), a simple two-step process is adopted in this study for estimating price variance and covariance. The two-step process is based on the decomposition of the conditional covariance matrix into conditional standard deviations and correlations. Engle and Sheppard (2001) proved that the two–step estimator is consistent. Price variance and covariance matrix will be used to calculate aggregated price risk index using economic index number theory later in this Chapter. Within the two-step framework, firstly either the univariate GARCH model, the Multiplicative Heteroskedasticity model, or the naïve expectation-based model is used for quantifying the first and second moments of each commodity price separately.

Standardized residuals from the first step are used to estimate the conditional correlation which is assumed constant over time as in Bollerslev (1990)'s Constant Conditional Correlation (CCC) model[1]. Price covariances are then calculated for each time period based on the conditional correlation and standard error obtained from the first step. A time-varying covariance matrix is obtained by stacking all periods together finally. The assumption of CCC has been commonly employed to simplify the estimation of multivariate GARCH models, even though the assumption is presumably wrong. Procedures for testing the CCC hypothesis have serious defects (e.g. see Shadat and Orme 2011 for a recent survey). Instead, we will later (in Appendix Two) estimate an alternative model with time varying conditional correlations and note that this does not change our main results. So the assumption of CCC does not seem to be too restrictive for our purposes.

2.3.1.a GARCH Models

Price is specified as a linear function of a multi-period lag in price,

$$P_t^i = \beta_0^i + \sum_{l=1}^{n} \beta_l^i P_{t-l}^i + \varepsilon_t^i \tag{2.1}$$

Univariate GARCH (p,q) models are specified for each separate price of the four commodities P_t^i assuming a conditional error process

$$\varepsilon_t^i = v_t^i {h_t^i}^{1/2} \text{ and } h_t^i = \alpha_0^i + \sum_{m=1}^{q} \alpha_{t-m}^i {\varepsilon_{t-m}^i}^2 + \sum_{n=1}^{p} \varphi_{t-n}^i h_{t-n}^i \tag{2.2}$$

$i = 1,2,3,4$

$\varepsilon_t^i = y_t^i - \mu_t^i(y_t^i)$,

v_t^i is a white-noise process with $E(v_t^i) = 0$ and $\operatorname{var}(v_t^i) = 1$

[1] Bollerslev (1990) proposed the Constant Conditional Correlation (CCC) GARCH model to resolve the difficulty of estimating a high number of parameters for multivariate GARCH models. The CCC model assumes that the conditional correlation matrix Rt is constant over time, e.g. Rt = R where R is the conditional correlation matrix of the standardized residuals.

h_t^i is the conditional variance of ε_t^i

t = 1,…,T

According to the simple two-step process, parameters are obtained from the above process first. The standardized residuals v_t^i are estimated as

$$v_t^i = \frac{\varepsilon_t^i}{h_t^{i\,1/2}} \tag{2.3}$$

Assuming constant conditional correlations for ε_t^i, (v_t^i, v_t^j) are used to estimate correlation between (v_t^i, v_t^j) as follows

$$r_{ij} = cor(v_t^i, v_t^j) \tag{2.4}$$

Where r_{ij} is the estimate of constant correlation across time.

r_{ij} and h_t^i are used to calculate time-varying conditional variance and covariance.

$$\operatorname{cov}(\varepsilon_t^i, \varepsilon_t^j) = r_{ij} * (h_t^i * h_t^j)^{1/2} = \operatorname{cov}_i^{ij} \tag{2.5}$$

The time-varying monthly variance and covariance obtained from GARCH models are written into a matrix, Vp_t in this study.

$$Vp_t = \begin{vmatrix} \operatorname{var}_t^1 & \operatorname{cov}_t^{12} & \operatorname{cov}_t^{13} & \operatorname{cov}_t^{14} \\ \operatorname{cov}_t^{21} & \operatorname{var}_t^2 & \operatorname{cov}_t^{23} & \operatorname{cov}_t^{24} \\ \operatorname{cov}_t^{31} & \operatorname{cov}_t^{32} & \operatorname{var}_t^3 & \operatorname{cov}_t^{34} \\ \operatorname{cov}_t^{41} & \operatorname{cov}_t^{42} & \operatorname{cov}_t^{43} & \operatorname{var}_t^4 \end{vmatrix} \tag{2.6}$$

t=1,…,T

2.3.1.b Multiplicative Heteroskedasticity Model

Construct a linear price model,

$$P_t^i = \beta_0^i + \sum_{l=0}^{n} \beta_l^i P_{t-l}^i + u_t^i \tag{2.7}$$

with error terms of the form,

$u_t^i = c_t^i \varepsilon_t^i$
$i = 1,2,3,4$
$\varepsilon_t^i \sim i.i.d.$ with $E(\varepsilon_t^i) = 0$ and $Var(\varepsilon_t^i) = \sigma^{2i}$
Assume that $c_t^i = \exp\left\{x_t{}' \theta / 2\right\}$ as shown in Greene (1997) so that

$$\sigma_t^{2i} = \sigma^2 \exp\{z_t' \theta\} \tag{2.8}$$

where $z_t = x_t$ (t=1,…,T)
P_t^i is a T$\times$1 vector of price of commodity i,

θ is a $p \times 1$ vector of price parameters

z_i is a p$\times$1 vector of independent variables, typically lagged prices, which are hypothesized to related to price variability

Harvey's standard multiplicative heteroskedasticity model has been widely applied in applied econometrics.[2] Under the assumption of normality, the following log-likelihood function is used to solve for unknown parameters β and θ in the model:

$$\log L = \frac{n}{2} \log 2\pi - \frac{1}{2} \sum_{i=1}^{n} z_i' \theta - \frac{1}{2} \sum_{i=1}^{n} e^{-z_i' \theta} (P_t^i - \sum_{p=0}^{n} \beta_p^i P_{t-p}^i)^2 \tag{2.9}$$

The simple two-step process illustrated by equations (2.3) to (2.6) is then used to calculate price variance and covariances of grain portfolio based on the parameters from the M Het models.

2.3.1.c Naïve Expectation-Based Method

The traditional naïve expectation-based method assumes that the expected price is the market price lagged one period. Similar to other studies (Chavas and Holt 1990; Coyle 1992; Haile et al. 2003), price variance and covariance of crop i and j are quantified as the sum of squares of the prediction errors of the previous three

[2] For a detailed understanding of this model and its many variations, see Harvey (1976, 1990).

periods with declining weight of 0.50, 0.33 and 0.17[3].

$$E_{t-1} p_t^i = p_{t-1}^i \tag{2.10}$$

$$\begin{aligned} \mathrm{cov}_{t-1}(p_t^i p_t^j) = {} & 0.50 * (p_{t-1}^i - E_{t-2} p_{t-1}^i)(p_{t-1}^j - E_{t-2} p_{t-1}^j) + \\ & 0.33 * (p_{t-2}^i - E_{t-3} p_{t-2}^i)(p_{t-2}^j - E_{t-3} p_{t-2}^j) + \\ & 0.17 * (p_{t-3}^i - E_{t-4} p_{t-3}^i)(p_{t-3}^j - E_{t-4} p_{t-3}^j) \\ & i, j = 1,2,3,4 \end{aligned} \tag{2.11}$$

Lastly time-varying price variance and covariance matrix of grain portfolio is constructed using the simple two-step process and the parameters estimated from the naïve approach.

2.3.2 Calculating Index of Aggregate Price Risk

The revenue aggregate V for a given collection of items in a single time period is computed as

$$V = \sum_{i=1}^{n} p_i y_i = py \tag{2.12}$$

Where p_i represents the price of the ith item

y_i represents the corresponding quantity

A fundamental goal of standard index number theory is to decompose the change in a revenue aggregate, V_1 / V_0 for time period 0 and 1, into the product of a part that is due to price change and a part that is due to quantity change. This implies

$$V_1 / V_0 = p_1 y_1 / p_0 y_0 = (P_1 / P_0)(Y_1 / Y_0) \tag{2.13}$$

[3] Several alternative sets of declining weights i.e. (0.7, 0.2, 0.1), (0.6, 0.25, 0.15) and (0.5, 0.3, 0.2) have been seen in the literature. Brorsen et al. (1987) found that using different sets of weights had an incidence on the risk analysis on U.S. rice farmers' income. Chavas and Holt (1990) indicate that (0.5, 0.33, 0.17) fared well in terms of key statistics results, but that their results were robust to changes in weighting scheme.

Moving to revenue risk aggregation, similarly a fundamental goal of index number theory for aggregating price risk is to decompose the change of revenue risk between two periods into its price risk change components and quantity change components (Coyle 2007)[4]. Price risk and output level jointly contribute to revenue risk as $y^T V_p y$, where V_p is the price variance and covariance matrix and y is a vector of output. It implies the change in revenue risk between two periods, $y_1^T V_{p1} y_1 / y_0^T V_{p0} y_0$ could be decomposed into a price risk change part VP_1 / VP_0 and a quantity change part Y_1 / Y_0. The following equation must hold:

$$(VP_1 / VP_0)(Y_1 / Y_0)^2 = y_1^T V_{p1} y_1 / y_0^T V_{p0} y_0 \qquad (2.14)$$

Where VP_1 / VP_0 denotes an aggregate price risk index over two period

Y_1 / Y_0 denotes an aggregate quantity index over two period

y_1 and y_0 denote output vector at time period 1 and 0 respectively

V_{p1} and V_{p0} denote conditional variance and covariance matrix of price at time 1 and 0 respectively

Then an aggregate price risk index can be obtained

$$VP_1 / VP_0 = (y_1^T V_{p1} y_1 / y_0^T V_{p0} y_0) / (Y_1 / Y_0)^2 \qquad (2.15)$$

In practice Y_1 / Y_0 can be approximated as a standard output quantity index, for example, Tornqvist quantity index, Fisher quantity index, or Laspeyres quantity index[5].

[4] For a detailed understanding of standard economic approach to index theory, readers are suggested to read Diewert (1976). For details of extension to risk, see Coyle (2007).

[5] Quantity index measures the overall change in quantities between the two periods. Laspeyres quantity index is defined as $q_L(p^o, p^1, q^o, q^1) = \sum_{i=1}^{n} p_i^0 q_i^1 / \sum_{i=1}^{n} p_i^0 q_i^0$. Paasche quantity index is

In contrast to the above, the standard approach to measuring aggregate price risk is to first calculate an aggregate price risk index (e.g. Tornqvist, Fisher, Laspeyres) and from this estimate aggregate price risk, e.g. by estimating a univariate GARCH model of aggregate price. This approach is simple but it introduces errors in aggregation over commodities, as discussed above.

2.4 Results

This study uses monthly prices (Yuan/Kg) for rice, wheat, corn, and soybeans collected from 156 county free-trade markets across China by the Ministry of Agriculture of the Republic of China. The price data is available from 1987 to 2007. The time series plot of the data is presented in Figure 2.1. Descriptive statistics and correlations for each commodity price are presented in Tables 2.1 and 2.2, respectively. The high correlations between market prices as well as patterns in price movements over time indicate that it is crucial to include both price variance and covariance into the aggregation of price risk over major agricultural commodities in China. Annual output (10,000 tons) data (1987-2007) are from the National Bureau of Statistics. Descriptive statistics for each commodity quantity are reported in Table 2.3. Statistical analyses are undertaken using the software R, Shazam, and Eviews.[6]

Least squares are initially used to estimate AR process, equations (2.1) and

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defined as $q_P(p^o, p^1, q^o, q^1) = \sum_{i=1}^{n} p_i^1 q_i^1 / \sum_{i=1}^{n} p_i^1 q_i^0$. Fisher quantity index is defined as $q_F(p^o, p^1, q^o, q^1) = q_L(p^o, q^o, p^1, q^1)^{1/2} q_P(p^o, q^o, p^1, q^1)^{1/2}$. Tornqvist quantity index is the geometric average of the quantity relative of the current to base period quantity weighted by the arithmetic average of the value shares for the two periods and is defined as $\ln q_T(p^o, p^1, q^o, q^1) = \sum_{i=1}^{n} \frac{1}{2}(s_i^0 + s_i^1)\ln(\frac{q_i^1}{q_i^0})$, where revenue share $s_i^t \equiv p_i^t q_i^t / \sum_{j=1}^{n} p_j^t q_j^t$.

[6] Unit root test results are inconclusive. For the Augmented Dickey Fuller (ADF) test, the null hypothesis of unit roots was rejected at 5-15% significant level for 3 of the 4 crops. Since ADF test has low power, the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test was also conducted. The null hypothesis of stationary was not rejected at 1% level for any crop, was barely rejected at 5% level for 2 crops, and was rejected at 10% level for the other 2 crops. So no corrections were made for unit roots.

(2.7). The constant variance assumption associated with (1) and (7) is tested using ARCH test, Harvey test, Glejser test, and White(B-P-G) test for heteroskedasticity in Shazam. Since the form of heteroskedasticity is unknown we conduct alternative tests for heteroskedasticity. The ARCH test for ARCH versus no heteroskedasticity, the Harvey test that tests for multiplicative heteroskedasticity versus no heteroskedasticity, and the White test, a general test for heteroskedasticity versus no heteroskedasticity when the form of heteroskedasticity is unknown, are conducted. In general the null hypothesis of no heteroskedasticity is rejected at standard significance levels (all 16 test results are significant at conventional levels). Strong evidence of heteroskedasticity is found for each commodity price model according to these test statistics, which are reported in Table 2.4.

General-to-specific modeling approach is conducted to specify the number of lags for both GARCH models and the M Het model to find a better fit for each commodity price. Maximum likelihood estimates of the four GARCH (1,1), equation (2.1), and the M Het Model, equation (2.7), are reported in Tables 2.5 and 2.6, respectively. The time-varying pattern of grain price variability is confirmed based on the estimated results. In GARCH models, the coefficients on ε_t^2 and h_t in the variance equation are both statistically significant at 1% significance level in all cases. In M Het models, the coefficients on lagged price in the variance equation are also individually statistically significant at conventional levels in all cases. Estimates of constant conditional correlations were calculated as discussed above, and are reported for GARCH and M Het models in Tables 2.7 and 2.8, respectively. Constant conditional correlations between standardized residuals in all four cases are positive, and the degree of conditional correlation is relatively higher between rice price and wheat price.

Then aggregate price risk indexes, equation (2.15) are constructed using price variance-covariance matrix V_p for all three models (GARCH, M Het, and Naïve), and using three aggregate quantity indexes Y_1/Y_0 (Tornqvist, Fisher, and Laspeyres). Aggregate risk indexes can be constructed as fixed base VP_t/VP_0 (or chained moving base VP_t/VP_{t-1}) and here July of 1987 was selected as the fixed base. Table 2.9 reports correlations between these aggregate risk indexes for GARCH models and the three quantity indexes. $\mathrm{VP}^{\mathrm{TornG}}$, $\mathrm{VP}^{\mathrm{FisherG}}$, and $\mathrm{VP}^{\mathrm{LaspG}}$ denote aggregate indexes of price risk formed from equation (2.15) using GARCH model and Tornqvist quantity index, Fisher quantity index, and Laspeyres quantity index respectively. These three aggregate price indexes are highly correlated with correlation ranging from 0.99711 to 0.99954. The near perfect correlation between aggregate price risk indexes related to alternative output index suggests that any of the three quantity indexes is adequate for our purposes (in principle the Laspeyres index is inferior to the other two). Similar results hold for the M Het and naïve models. So in the rest of this study, we only consider a Tornqvist output quantity index.

Aggregate price risk indexes are plotted in Figure 2.2. Correlations between those price indexes are provided in Table 2.10. $\mathrm{VP}^{\mathrm{TornG}}$ denotes the aggregate price risk index, when the second moment of each commodity price is estimated by a GARCH model, as presented by equation (2.2). $\mathrm{VP}^{\mathrm{TornM}}$ is an aggregate price risk index in which the price variance is quantified by M Het model, as depicted by equation (2.7). $\mathrm{VP}^{\mathrm{TornN}}$ denotes the aggregate price risk index based on Naïve expectation approach, as represented in equations (2.9) and (2.10), to measure price variance and covariance. The correlation is highest between the GARCH and Naïve models. Aggregate indexes vary considerably across methods of estimating individual commodity price risk. Table 2.11 compares superlative aggregate price risk indexes with simple univariate measures. Here VP^{TornSG} is the aggregate price risk obtained from univariate GARCH model of Tornqvist price index over commodities; VP^{TornSM} is aggregate price risk from univariate M Het model of Tornqvist price index; and VP^{TornSN} is aggregate price risk obtained from simple naïve expectation-based approach based on Tornqvist price index. The correlations between price risk indexes for GARCH models is only 0.37, and for M Het models is 0.31. Presumably this large difference reflects at least in part errors in aggregation in the simple approach. The correlation between price risk indexes based on naïve expectation-based approach is much higher at 0.89. Perhaps, this is because the simple naïve approach does not involve any aggregation errors in econometric models, as there is no econometrics. These results indicate that the economic index number approach to aggregating price risk over commodities leads to quite different empirical measures of aggregate price risk than does the simple approach, at least for this data set. These are similar to results in Coyle (2007) for Manitoba crops (differences in results between correct and simple approaches to aggregation are more pronounced here). One secondary issue is considered here. Appendix Two relaxes the CCC assumption and instead estimates a time varying conditional correlation multivariate GARCH model, namely a diagonal BEKK model. The variance and covariance estimates are similar to estimates for the CCC model (except for soybeans, the more minor the four crops). Moreover a superlative aggregate price risk index based on BEKK estimates is highly correlated with an aggregate price risk index based on CCC estimates: a correlation +0.97. These results suggest that the CCC assumption is adequate for our purposes[7].

[7] We also conduct multivariate GARCH under CCC using the one-step approach to estimation originally proposed by Bollerslev (1990). The coefficients for CCC are all significant at 1% level and the correlation between the aggregate risk index obtained from the one-step CCC model and the one obtained from 2-step multivariate GARCH model is 0.98.

2.5 Conclusion

This paper compares alternative approaches for measuring aggregate price risk over Chinese major grains. The superlative aggregate price risk index is emphasized since it uses index number theory appropriately in incorporating both variances and covariances of price risk. High correlations between aggregate price risk indexes constructed using different outcome quantity indexes are observed. Using the same output quantity index (Tornqvist-type), aggregate price risk indexes are compared across approaches to measuring price risk. The empirical results obtained here reveal positive correlation across alternative approaches. For GARCH and M Het models, correlation between superlative aggregate price risk indexes and simple univariate measures are low. Thus the theoretically superior measure of aggregate price risk is also quite different from the simple measure, at least with this data set.

As a pioneer study this paper has important implications for quantifying aggregate price risk over commodities in the case of Chinese major grains. Many research issues still remain. For example, this research could expand the scope by incorporating price risk of livestocks such as hogs, which heavily rely on major grains as input in China so price variation of major livestocks may be highly correlated with major grains in China.

CHAPTER THREE: EXPLAINING AGGREGATE PRICE RISK FOR MAJOR GRAIN COMMODITIES IN CHINA

Abstract

The previous chapter measures aggregate price risk by using GARCH models, Multiplicative Heteroscedasticity (M Het) model, and traditional Naïve expectation-based heteroscedasticity methods in the spirit of economic index number theory, but does not explain price risk. Prior to this study, the only econometric studies attempting to explain aggregate risk are limited to models of stock market return volatility. This chapter attempts to investigate potential factors that contribute to aggregate price risk of major grain products (rice, wheat, corn and soybeans) on monthly base in China from mid 1980s to recently. Superlative price risk indexes are explained by a set of key variables that characterize China's economy, agricultural market and trade as well as biological system of major grain in China. These variables account for much of the variation in the aggregate price risk index. Moreover this model has better fit than does a model using a standard simpler measure of aggregate price risk. Thus empirical results support use of the more theoretically correct approach to measuring aggregate price risk adopted in this thesis.

Keywords: China, Grain Market and Trade, Aggregated Price Volatility, Drivers

3.1 Introduction

The subject of price volatility for major grains in China has received increased attention recently for risk management strategies and policy implementations. Major grain (rice, wheat, corn, and soybeans) production, consumption, and trade account for a significant share of China's food system. Grain price variation has large effects on producers, consumers and other market participants. Since 1978 when market oriented reforms and the opening door policy to international trade were implemented, China has gradually adopted various policies to promote free trade of agricultural products. Among those policies, some were known as retrenchment, some as acceleration and others as ambiguity. Moreover, China's rapid economic growth and gradual transition towards a market economy have changed domestic production and consumption patterns and trade behavior significantly in agricultural industry. Consequently prices of agricultural products, especially grains, have fluctuated throughout the last three decades. Farmers make production decisions by responding to both level and volatility of prices. Price uncertainty will lead farmers to be cautious in applying costly inputs and this will tend to decrease output. Rozelle and Huang (1998) indicated that China's farmers could increase (decrease) output as they face less (more) price risk and uncertainty.

It is, therefore, important to understand the grain price volatility and investigate the potential factors contributing to grain price risk in China. However, studies on China's major grain price risk are limited, particularly with regard to farm level grain prices. Some existing studies discuss agricultural commodity price in China more from policy regulatory and marketing development and reform perspectives (Huang and Rozelle 2006; Brauw 2004). Relatively little is written about the quantitative impacts of economic factors and agricultural and trade policy changes on price risk of major agricultural commodities. Some quantitative studies attempt to analyze price volatility for individual grain in China in recent year. Du and Wang (2004) apply time series models to describe price behavior of China's wheat using wheat futures data. No studies analyze price risk for China's major grains portfolio by considering the tight relationship in production and consumption among a group of grains.

This paper is the first effort to explore key factors that may affect price volatility for China's key grains portfolio including rice, wheat, corn and soybeans from both theoretical and empirical perspectives. As the most important agricultural commodities in China, these 4 crops jointly account for over 90 per cent of China's grain supply, and contribute about 60% of the yearly average net income for China's farmers according to National Bureau of Statistics (NBS). It is also rational to analyze price risk for a group of grains since those crops are partly substitutable in both production and consumption. The crop production distribution map (see Figure 3.1) shows all four crops are widely produced in most of provinces in China. The crop calendar for these four grains illustrated in Figure 3.2 shows similar planting, growing, and harvesting season across crops. Over the past decades, prices of major grains peaked together in 1988, mid of 1990, mid of 2000 (see Figure 3.1 in Chapter 2). The special features of Chinese economy and complex characteristic of reform strategies make the task of explaining price risk important and challenging. The dual price system in China contributes complexity to the study. Since early 1980, the Chinese farmers have faced two prices: the government procurement prices[8] (quota prices and negotiated prices) and market prices. This paper focuses on market prices since the risk portion from market factors continues increasing as the scope of government planning reduces over time. The impact of China's WTO accession in 2001 on price risk is worthy of assessment. After that the Chinese government started

[8] Quota prices were set by the government annually. In principle, negotiated prices were slightly below market prices. Farmers' income and production decision making are generally influenced by both procurement and market prices. This paper focuses on market prices since the risk portion from market factors continues increasing as the scope of government planning reduces over time. For example, negotiated purchases as a proportion of total government purchases including both quota and negotiated purchases increased from 25% in 1985 to 50% in 1994 (Rozelle and Sumner 2003).

to rely more on market forces in agricultural products distribution. More wheat, corn, rice, soybeans, cotton and oil seeds are imported due to their higher prices on the domestic market. Chinese farmers face strong competition from cheap imported agriculture products after 2001, especially the significant impact of cheap grain products from abroad. This makes them more vulnerable to economic uncertainty and risk.

There is a huge literature using GARCH models to measure risk, including econometric studies of risk in stock market returns and in agricultural product prices. Part of the attraction of ARCH and GARCH models is that measurement is based on a model of persistent patterns of risk over time rather than on a model explaining risk. In contrast, earlier models of heteroskedasticity generally required an explanation of heteroskedasticity, and such explanations are viewed as tenuous at best.

However there is almost no literature attempting to explain risk as measured by GARCH models. The one exception is in the area of stock market returns. Explanation of return volatility in terms of market fundamentals has been viewed as the most important remaining research issue in econometrics of stock market risk. Early attempts were unsuccessful (Schwert 1989), but there is a small recent literature reporting some progress (Diebold and Yilmaz 2007; Engle and Rangel 2008; Engle, Ghysels and Sohn 2008; Lettau and Ludviqson 2010). Apparently there are no other attempts to explain GARCH measures of price risk reported in the literature.

So this is the first study attempting to explain GARCH measures of price risk, aside from several studies of stock market volatility. Moreover this study uses a theoretically correct application of index number theory to construct measures of aggregate price risk. In contrast, in published studies, stock market volatility was estimated simply from e.g. a univariate GARCH model of aggregate returns.

This study attempts to explicitly measure and explain the impact of key elements on price risk for major grains in China, which is measured using superlative price risk index approach as presented in Chapter 2 of this thesis. Our exploration is motivated by the economic demand and supply theory, which suggests that the volatility of exogenous variables in the demand and supply system should be related to market volatility.

The plan of this chapter is as follows. The next section gives an overview of key reforms on grain marketing and trading system in China over the last three decades. The following section examines a series of factors that may have an important impact on Chinese grain sector from both theoretical and empirical point of view. Subsequently data and econometric models are discussed before the empirical results are presented and discussed. The last section concludes with the main findings of the study and suggestions for future research.

3.2 China's Grain Marketing and Trading System Reform

This section aims to provide a high level understanding of Chinese grain section by presenting an overview of grain marketing and trading systems in China over the last 30 years. Chinese government programs on agricultural production and rural development are under the Ministry of Agriculture, while agricultural trade is under the Ministry of Foreign Trade and Economic Cooperation. Therefore, the agricultural policies and trade policies have not always been consistent and well-coordinated. The government's agricultural policies focus on productivity, market stability, and development of rural enterprises, whereas the trading policies are more profit oriented (Chern and Yu 2002).

Before 1978 the Chinese government strictly controlled the production, marketing, and trade of major agricultural products with procurement prices generally below international prices in order to provide cheap food, capital, and labor for industrial development. Since 1978 the Chinese government has undertaken a number of gradual reforms of its grain marketing and trading system. Even though several "retrenched" policies were introduced during the reform period, these changes have promoted competition and efficiency in grain sector.

3.2.1 Overview of China's Grain Marketing System

China's policy reforms in agriculture can be divided into several major episodes (Wu and McErlean 2002; Huang and Rozelle 2006). Major reforms of the Chinese grain marketing system happened between 1978 and 1985, and were aimed at continuously raising farm level procurement prices and gradually liberalizing rural markets (Huang and Rozelle 2006). The second phase of marketing reforms beginning in 1985 to 1992 aimed mainly at diminishing government intervention in the grain sector and at further enlarging the role of market allocation. The compulsory purchase system was partly replaced by the contract purchase system. The government's pure monopsony on grain was replaced by a dual system of government procurement and market exchange. After fulfilling the contracted quota at a price set annually by the authorities, grain growers could sell their remaining product to state grain bureaus (SGBs) or grain processors at negotiated prices, or directly to consumers on the free trade market.

In the late 1980s, the government began to reduce the scope of ration sales due to its high grain subsidies[9] and to improve the economic efficiency of grain markets.

[9] From 1985 to 1992, quantity of ration sales was 1.1 billion tons more than procurement amount. The sales shortfall was filled by negotiated procurement quantity. Since negotiated prices were higher than the sales prices of "rationed sales", the government had to subsidize a lot of the grain

The rationed sales were reduced and the prices of rationed sales were increased to a level consistent with government purchase prices. Meanwhile, after fulfilling the state procurement, storage, and sales plan, SGBs were allowed to trade in free market. This situation continued until the beginning of the 1998 grain reforms, which aimed at strengthening state control over the national grain system away from market allocation and only allowed the SGBs to purchase grain from farmers.

A third period of reform is from 1993 to 1998. During the beginning of this period, China opened its grain market gradually and grain prices started to reflect movements in the domestic market demand and supply. In early 1993, many provinces began to discontinue the grain ration sales that allowed urban consumers to purchase grain at low fixed prices. However, reform policies were retrenched after a sharp increase in grain prices spread from the coastal areas to the whole country in late 1993 and mid 1994, which was interpreted as a result of the recent policy reform and grain product shortfall. As a result, the procurement quota price was set lower than the market price by the government again; the so called Governor's Rice-Bag Responsibility System (Mi Dai Zi Sheng Zhang Ze Ren Zhi)[10] in local grain supply was introduced in 1995; the rationed sales prices were restored and rationed sales prices were fixed at a level lower than the market price. The double-track system was resumed in purchasing and marketing. In 1996, due to high international grain prices, the government sharply increased quota prices for grains in order to stimulate grain production to assure adequate grain supplies.

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marketing in order to cover the sales cost and associated high running cost (see 211 项目科研组 "中国农产品流通的制度变迁—— 制度变迁过程的描述性整理" 中国人民大学农业经济, 2004) In 1990, the subsidies to government grain marketing accounted for 6.7% of the budget (Wu and McErlean 2002).

[10] The Governor's Rice-Bag Responsibility System (Mi Dai Zi Sheng Zhang Ze Ren Zhi) is a policy designed to promote self-sufficiency in domestic grains at the provincial level. With this policy governors were to stabilize grain sown area, improve crop yields, maintain local grain stocks, stabilize grain prices and use local revenue to subsidize the procurement quota price in the event of a disaster.

After 1998, grain marketing reforms were launched more and restrictions on marketing were removed (Huang, Rozelle, and Chang 2004). Most commodities are traded by private traders and commercialized state grain bureaus (Sicular 1995). Since China's WTO accession in November 2001, the Chinese government has started to rely more on market forces in agricultural products distribution.

3.2.2 Overview of China's Grain Trading System

Prior to China's foreign trade reform in late 1970s, almost all of China's foreign trade was strictly dominated by central planning and operated by a small number of foreign trade corporations. China's merchandise trade since the market reform has been characterized by decentralization of foreign trade, reductions of trade barrier, progress on currency convertibility, and so on. However, China's agricultural trade, especially grain trade, hasn't been liberalized to the same extent as its trade in manufactures (Carter and Li 2002).

China's grain trade has major consequences for both China's domestic grain market and international grain market. International grain trade has helped balance supply and demand and also the grain varieties in the domestic market. China's main exporting crops are rice, beans, and corn. The most important importing crop is wheat from 1978 to 1990s, in which Canada, United State, and Australia are three major wheat exporters. However, after WTO accession, China's soybeans imports surged. Since early 1990s, China's grain trade has entered a new transitional period. There were large fluctuations of grain exports and imports. Also the grain trading pattern has been changed from the simple exporting rice and importing wheat to multi-commodity trade (Wu 2002). Between 1994 and 1995, China switched from being a large exporter to being a large importer of grain. After 1995, the grain trade pattern changed sharply and was characterized by decreased imports and increased exports.

After China's entry into the WTO in November 2001, China engaged more in the global grain trade, and its grain trade procedure has become more efficient. China's grain trade has been stabilized, and has become more market-oriented and based on comparative advantage.

3.3. Theoretical and Empirical Motivation

This section evaluates variables that may have an important impact on price, and hence price volatility, via Chinese grain supply and demand from both theoretical and empirical perspectives. The principle in choosing variables for explaining price volatility is that the variable enters either the grain supply or demand equation and behaves exogenously. Market prices respond to shifts in supply and demand, and the degree of price response is associated to the price elasticity of both. Practically given the special features of China's grain marketing and trading system over the last 30 years, factors in explaining volatility of grain prices should include market liberalization and development, trade liberalization, agricultural and trade policy changes in China. Candidates being discussed and evaluated in this section include infrastructure development, major agricultural marketing policies, grain quota, international grain trade, exchange rate, weather, consumer income, and grain input cost.

3.3.1 Infrastructure Development Index

In general, infrastructure development increases domestic inter-regional trade and may reduce price variability as local price fluctuations could be comforted by trading with remote regions that are less affected by the shock. Feinberg (2000) examines how market-oriented infrastructure affects market performance for three developing countries-Colombian, Korea and Morocco; Feinberg and Meurs (2005) conduct a similar study for 13 industry sectors in Bulgaria, Hungary, Poland, Romania, and Slovenia. The paper by Yu (2007) evaluates the impact of infrastructure evolution on prices for 14 broad industry sectors in China. Those studies quantify infrastructure to capture the response of prices to aggregate supply and demand trends in the economy. They also state that market-oriented infrastructure development promotes market competition by reducing transaction and transportation cost on inter-regional trades. Their results find that market reform and infrastructure development do influence domestic prices although the degree of impact depends on development or transition level of the economy and nature of the industry.

China's rural reform policy is characterized by its effort to liberalize domestic grain markets and periodical retrenchment on its liberalizing reforms in 1990s. Sicular (1995) and Rozelle and Huang (1998) indicate that these significant shifts in China's rural policy might affect market prices as well as price risk. In this study, the methodology of measuring physical infrastructure development[11] is similar to that presented by Yu (2007). The proxy of infrastructure development of China incorporates four measurements: the development of the transportation (railway transportation, highway transportation, and air transportations) and telecommunication sector, in the past three decades. This is used as a measure of

11 Definition and measurement of infrastructure vary by literature. Carlin, et al. (2003) define infrastructure using institutional and personal capacities; Demurger (2001) measures infrastructure using education and health care; Zhuravskaya (2000) and Feinberg and Meurs (2005), Yu (2007) use transportation and communications as representative of infrastructure. Index of railway transportation development is equal to stock of railway locomotives (excluding steam locomotives)*length of railways in operation/population; the index of highway transportation development is equal to number of civil motor vehicles*length of highways/population; the index of air transportation development equals (number of civil airports * number of civil aircraft)*length of civil aviation routes/population; the index of telecommunication development equals number of phones (including cell phones)/population.

infrastructure development.

3.3.2 Major Agricultural Marketing Policies

Since 1978 when market oriented reforms and the opening door policy to international trade were implemented, China has adopted various policies to promote free trade of agricultural products. Among those policies, some were known as “retrenchment”, some as acceleration, while others as ambiguity. Major policies are illustrated in this section chronologically.

During 1991-92, the central government implemented nationwide policies that reduced its’ authority over the control of grain. It let farmers sell their grain on the open market after they had delivered over to the government their contracted amount of grain. Many literatures indicate that the reforms in the early 1990s appear to have succeeded in increasing the integration of rural China’s commodity markets. Rozelle et al. (2008) present statistical evidence on the positive impact of these economic policies on market integration by looking at the decreased price variation of rice and maize among markets across time.

In 1995, the Rice Bag responsibility system was introduced in order to increase grain production. This led to stable grain production and a significant reduction on short run price fluctuation, according to a few studies (Findlay and Chen 1999).

China implemented a new grain marketing and stock-holding policy in April 1998. Individuals and private companies were prohibited from purchasing grain from farmers directly. Commercial bureaus and the grain reserve system should be the only ones to purchase grain from farmers. This grain marketing policy raised a lot of concerns and debates among policy makers and scholars (Findlay and Chen 1999;

Nyberg and Rozelle 1999). The direct reasons for 1998’s reform are an excess supply of grain production, low price and large deficit with state grain agencies. A positive impact on aggregate price risk index is anticipated.

It was widely discussed that China’s WTO accession in December 2001 would have both positive and negative impacts on the domestic agricultural market. It would lead to rising grain imports as the Government opened low-tariff import quotas for rice, wheat, corn, cotton, sugar, and wool and pushed through further reforms in China's grain distribution and circulation system. Also increased import of agricultural products that are land-intensive would help readjust the agricultural infrastructure in areas with a shortage of land resources. However, China’s grain prices were generally higher than international grain prices and China’s agriculture is predominantly composed of small-scale farming, which seems vulnerable to competition from larger international farmers. Overall, the expected impact of China’s WTO accession on domestic grain market, and then grain prices, seems ambiguous. Policy variables are introduced into the econometric model as dummies to capture the time span when a significant agriculture policy was implemented.

3.3.3 Procurement Quota

There are different opinions about possible impacts of procurement quota quantity on grain production, according to Sumner and Rozelle (2002). On the supply side, there are many theoretical and quantitative studies on the possible impact of procurement quota quantity on grain production (Lin 1993; Putterman 1992; Wang, Huang, Sumner, and Rozelle 2002). However, little in the literature has focused on the possible effect of mandatory quota policies on grain price risk. This chapter presents the first effort to measure the impact of quota on grain price risk.

Since the open-door policy reform in 1978, the relative importance of quota purchases has continually decreased. After the reform in 1985, the new national quota was only about 10% of national total production. The rest of government grain requirements were to be purchased directly from farmers at negotiated prices (Wang and Davis 2000). During later 1990s and early 2000s, grain procurement system was eliminated in most of provinces and in 2004-2005 this system was abolished nationwide. However, as a policy instrument, the changes of annual delivery quota affect farmers' production behavior both in the short term and in the long term.

Wang, Huang, Sumner and Rozelle (2002) test the effect of the quota on the market price by assuming a price signaling effect. They speculate that a government leader who is responsible for maintaining food production will adjust the quota levels to induce farmers to produce more or deliver more to the government if he observes either falling market prices of the output or rising prices for inputs. Following Wang, Huang, Sumner and Rozelle's assumption, we shed light on the possible effect of the procurement quota on market price risk.

3.3.4 Degree of International Trade Participation

International trade is considered as a measurement of degree of market integration between Chinese and global markets. During the last 30 years under market-oriented reform, China's volume of international grain trade has increased significantly while the proportion of grain trade in total international trade is decreasing over time. Long (1999) argues that it is inappropriate for previous researchers to pay little attention to the impact of international trade on China's domestic market and to believe that the international grain trade is just a small portion of domestic production[12]. Long demonstrates a substantial influence of international grain trade on China's domestic market by providing strong empirical evidence from the wheat sector, with wheat imports accounting for around 30% of market supply[13], the contribution of import variation on total supply variation in the domestic market was more than 50% in most years from 1980s to 1990s, and there is a strong correlation between wheat imports and domestic prices. More literature has discussed how the Chinese government has used international market to maintain a domestic market equilibrium such as Long (1999), and Wu (2002).

Inspired by Long (1999) and Wu (2002), this paper evaluates the impact of China’s growing participation in the world agricultural market on domestic grain prices risk by extending the scope from a single grain to grain portfolio. The ratio of total volume of grain trade over total volume of grain production is chosen as a measure of the degree of China’s participation in world grain trading. Theoretically this candidate variable is expected to come out the price risk model significantly but the sign of the coefficient is ambiguous which depends on the price elasticity of supply and demand. Furthermore reasonable lagged effect of the degree of international trade participation on domestic grain price volatility is anticipated.

3.3.5 Foreign Exchange Rate

After a long period of fixed exchange rate with the U.S., in 2006 the Chinese government let Chinese yuan appreciate, under pressure from the U.S. government

[12] According to Long (1999), the reason for this apparent discrepancy is China's dualistic economy with a highly autarkic agricultural sector. Because only one-third of total production enters market circulations, the remaining two-third of the grain is consumed by rural households themselves.

[13] According to Long (1999), annual wheat imports were only about 10% of domestic production, but they accounted for approximately 30% of the market supply. The ratio was quite high among the world's other countries.

due to the large trade deficit between the two countries. The Chinese government worries that the appreciation of the yuan would introduce more price pressure on its domestic market since the imported goods will be cheaper as the domestic currency appreciates, forcing domestic producers of the import competitive good to decrease prices as well. That is, foreign exchange rate changes will not only affect import and export prices but will also affect domestic prices of traded goods.

After China's WTO accession in 2001 more wheat, corn, rice, soybeans, and other agricultural commodities were imported more due to their higher prices on the domestic market. Chinese farmers face strong competition from cheap imported grain products, after 2001. This makes them more vulnerable to economic uncertainty and risk.

Yu (2007) sheds light on the effect of the effective exchange rate[14] fluctuations on domestic prices by examining the linkage between currency-value changes and annual price index of 14 broad industry sectors in China for the years 1980-2002. However, Yu's study doesn't include agricultural sectors and only explains how the changes of exchange rate affect the price level. This study examines the impact of changes in the effective foreign exchange rate on major grain prices risk in China. Also a time lag is expected between the change of foreign exchange rates and its' effect on domestic grain prices.

3.3.6 Weather Impact

[14] A nominal effective exchange rate index is the weighted average of a country's currency relative to an index or basket of other major currencies (expressed on the base 2000=100). A real effective exchange rate represents a nominal effective exchange rate index adjusted for the effects of inflation of the home country, selected country and euro area. The weights are determined by relative trade balances, in terms of one country's currency, with each other country within the index. In both cases of the indices, an increase in the index reflects an appreciation. See IMF web site for effective exchange rate explanation http://www.imfstatistics.org/imf/IFSExcha.htm

The effects of weather conditions on grain production have been found to be significant in both agronomic and econometric studies. Modern technologies such as massive water control infrastructures, advance inputs make crops more robust in unfavorable weather but the impact of weather is still crucial given the nature of agriculture industry, especially the grain sector which is more vulnerable to weather change. Most studies on impact of uncertain weather conditions on Chinese agricultural grains focus on the volatility of either grain yield or product growth (Kueh 1983; Carter and Zhang 1998; Bai, et al. 2010). Little research has been done to analyze the possible influence of weather-related factors on aggregate price volatility for major grains in China.

This study quantifies uncertain weather conditions using two types of weather variables: one is percentage of disaster areas affected by flood and/or drought in China, which represents temperature and precipitation factors, and the other is sunspot activities index as a representative of solar radiation. A positive lagged relationship between adverse weather conditions and price volatility is expected to reflect the indirect contribution of weather on grain prices variation via grain production.

The influence of temperature and precipitation on grain production and hence prices have been widely discussed and well accepted in previous literature. Recently, the effect of sunspot activity on production as well as prices of agricultural commodities has gained a lot of attention. William Hershel discovered the effect of sunspot activity about 200 years ago: the solar cycle affects climate and crop growth on earth by changing levels of cloud cover. Lower sunspot activity indicates lower yield and then presumably higher commodities price. Both agronomic studies and econometric studies have identified solar radiation as an important yield determinant (Daughtry, et al. 1983; Dixson, et al. 1994).

3.3.7 Other Factors

Agricultural seasonality in planting and harvesting is well observed in the agricultural economics literature as an important factor for commodity price variations. Previous research has confirmed the presence of strong seasonality in price volatility and also indicated that volatility of agricultural commodity prices have shown similar trend during the same period (Chambers et al. 1981; Deaton and Laroque 1992; Moschini and Hennessy 2001; Hale et al. 2013). In particular, volatility appears to peak in the summer months for most agricultural commodities. However, there is little literature investigating the seasonality pattern on aggregate price risk over commodities. In China, the four major crops (rice, wheat, corn, and soybeans) are partly substitutable in terms of production and consumption. Similar growing cycle of a group of grains is expected to influence the volatility of prices over the course of a calendar year. Typically corn and soybeans are planted in similar seasons, and have similar land requirement (see Figure 3.1 and Figure 3.2). So we investigate whether or not a seasonality pattern exists in aggregate price risk of key grains.

In addition to the factors already discussed, other factors such as input cost, and income per capita may also play a role in influencing grain price volatility. Input cost could impact grain price on the supply side while income per capita could contribute to price variation from the demand side.

3.4 Data and Model Specification

In order to evaluate and understand the impacts of key variables on aggregate price risk for major grains (rice, wheat, corn, and soybeans) in China for the period of

1986 to 2007 as outlined in the previous section, the paper collects a number of data from broad sources respectively.

Dependent variables are monthly level aggregate price risk indexes for the four major grains, which are constructed using alternative approaches in Chapter 2 of the thesis. Monthly nominal and real effective exchange rate indexes are from the International Finance Statistics (IFS). Annual data of railways, highways, aircraft, telecommunication as well as population needed for calculating an index of infrastructure development are sourced from National Bureau of Statistics of China. The infrastructure development index is the straight average of these four index components. Annual grain procurement quota data are collected from a survey[15] that was conducted in 25 counties in Zhejiang, Jiangsu, and Sicuan provinces in the late 1990s[16]. Annual data collected from China Statistical Yearbook, National Bureau of Statistics of China include import and export volume of rice, wheat, corn and soybeans, drought and flood area data, and income per capita. Both the level and standard deviation of monthly sunspot activities index are from Solar Influences Data Analysis Center, NASA. Average annual major input cost (labor, seeds, and fertilizers) of these four grains comes from Ministry of Agriculture of the People's Republic of China. Since monthly granularity data is not publicly available for those annual level variables, for this analysis purpose, monthly level data is calibrated by replicating annual value for each month within the year.

In this study, a time series multivariate regression model is employed to

[15] The author acknowledges Dr. Dewen Wang for providing the survey data, which was collected for the study of "Quota and Grain Production in China" with J. Huang, D. Sumner, S. Rozelle *Agricultural Trade and Policy in China: Issues, Analysis and Implications,* The Chinese Economy Series, Ashgate Publishing. ISBN 0-7546-3223-7. Quota volume collected from 25 counties in Zhejiang, Jiangsu, and Sicuan provinces as a representative of China's quota distribution and variation.

[16] Quota data is only available up to 1997. Quota data of 1998 and onwards are assumed to be 0 given that procurement quota system across provinces within China was abolished gradually since later 1990s.

examine whether a set of variables affects aggregate price risk index of grain commodities. Lagged dependent variables are specified to describe the mean level of price risk movement as we can see in most financial price time series models. The rest of candidate explanatory variables could enter the model in the form of the level, change of level, variance, or a mix of those, which depends on character of the variable. Infrastructure development index is expected to come into the model with the level due to the gradualness of Chinese economy and marketing reform. For those continuous economic variables such as effective exchange rate, grain quota, degree of international trade participation, and weather variables that may influence price, their variations potentially affect price risk. For example, if price, P, is related to continuous variables, Z, as $P = Z\beta$, the price risk V_P may be related to risk of Z, simply as $V_P = \beta^T V_Z \beta$, where V_Z is covariance matrix of risk for Z. This suggests that price risk is increasing in variances of Z. Variation of annual variables could be simply defined as change of value across years while variation of monthly variables could be measured elaborately by time series models and defined as variances of the time series. The approach for estimating the monthly variance of explanatory variable could be either univariate GARCH, M Het model, or traditional Naïve approach introduced in Chapter 2. Yearly dummies are introduced as part of the explanatory variables to indicate when the major policies were implemented. Monthly dummies are incorporated into model of aggregate price risk index to capture potential seasonality pattern.

Thus the price risk explanation model is specified as[17]

[17] More generally, we could specify an autoregressive distributed lag (ADL) model with lags in all explanatory variables as well as in dependent variable, VP. However we adopt this simpler model due to degrees of freedom and multicolinearity problems.

$$VP_t = \beta_0 + \sum_{i=1}^{m} \beta_i VP_{t-i} + \sum_{j=1}^{n} \beta_j x_{jt} + \sum_{k=1}^{w} \beta_k Policy_k + \sum_{l=1}^{11} \beta_l mnth_l + \varepsilon_t \qquad (3.1)$$

Here VP_t is the monthly aggregate price risk index of four commodities (rice, wheat, corn and soybeans) in China; VP_{t-i} is lagged dependent variable; x_{jt} denotes candidate explanatory variables in the form of either level, change, or variance; $Policy_k$ is dummy variable representing the impact of implementation of major policy reforms; and $mnth_l$ denotes monthly dummies. β s are coefficients to be estimated, and ε_t is the error term for time t.

3.5 Results

The results are split into three sections. First, analytical procedure and statistical approaches are introduced. Next, econometric results for VP^{TornG} model (a Tornqvist type aggregate of individual GARCH price risk and correlation) are particularly focused on because it is generated using precise approaches of interest in this study. Thirdly, the estimation results are compared across alternative models for further understanding of aggregate price volatility.

3.5.1 Preliminary Testing

First, both Augmented Dickey-Fuller (ADF) and Phillips-Perron unit root tests are conducted for monthly level time series including all price risk indexes, effective exchange rate, and solar radiation indexes. The two tests show similar results that all monthly variables (except sunspot activities) are stationary at level. Table 3.1 shows results of the tests.

Correlations among explanatory variables are low (Table 3.2). This suggests that multicolinearity is not likely to be a serious problem.

The study then considers the correlogram for aggregate price risk indexes to identify the lag of dependent variable by looking at autocorrelation function (ACF) and partial autocorrelation function (PACF) plots. As shown in Table 3.3.a, price risk index VP^{TornG} displays the classical pattern for AR (1) process with the autocorrelations dying out across lags and the partial correlation coefficient being significant only at lag 1. Tables 3.3.b to 3.3.f display correlogram plots of aggregate price risk indexes constructed by alternative approaches. Aggregate price risk index measured by other approaches also show similar AR process pattern as VP^{TornG}, except for VP^{TornM} and VP^{TornSM} .

3.5.2 Basic Results

The parameter estimates of the time series multivariate model are reported in Tables 3.4 to 3.6. Final estimates of the major model of interest with dependent variable VP^{TornG}, a Tornqvist-type index of aggregate price risk based on GARCH estimation for individual prices are reported in the first column of Table 3.4. The variables of interest include infrastructure development index, change of procurement quota volume between current year and last year, 6-month lagged variance of nominal effective exchange rate index, 6-month lagged standard deviation of sunspot activities index, 6-month lagged of degree of international trade participation, policies dummy presenting nationwide policies that reduced its' authority over the control of grain in 1991-92, policy dummy presenting implementation of Rice Bag responsibility system in 1995, and policy dummy presenting the execution of a new grain marketing and stock-holding policy in April 1998.

Most coefficients of interest in the VP^{TornG} model have the expected signs, reasonable lag, and acceptable t-ratios. The coefficient of infrastructure development index is significantly negative, suggesting that domestic trade liberalization helped reduce price volatility. The coefficient of change of quota volume, variance of effective exchange rate, and standard deviation of sun spot activities index are significantly positive as expected. The degree of international trade participation influences price variation significantly in a positive direction, which aligns with the assumption outlined in previous section. The coefficient of 1991-92 and 1995 policy dummies have an expected sign and reasonable t-ratios respectively. The coefficient of 1998 policy is reported with a negative sign as expected though insignificant, suggesting perhaps some positive influence to price volatility. Relatively large t-stat of most coefficients on monthly dummies suggests seasonality. The pattern of seasonality based on VP^{TornG} model is shown in Figure 3.3.a. Higher price volatility occurs from April to July, which is associated with uncertainty about supply during planting and growing seasons; lower price volatility occurs during harvest season, which is from August to November.

Aggregate price risk indexes constructed using alternative approaches presented in Chapter 2 are also explained by using the same set of variables as in the VP^{TornG} model. Estimation results are also presented in Table 3.4. Columns two and three also use a Tornqvist-type index of aggregate price risk, but risk for individual prices are estimated from the Multiplicative Heteroskadasticity (M Het) model and the Naïve models, respectively. Coefficients of the main variables of interest have the same signs (where reported) in the VP^{TornG} model, with fewer coefficients statistically significant. The last three columns are for models using the simpler (theoretically incorrect) approach where risk is measured directly from aggregate prices. Again coefficients of the main variables have the same signs as in the VP^{TornG} model, but fewer coefficients are statistically significant.

Elasticities at the means[18] for major explanatory variables of each alternative models are reported in Table 3.5. Elasticities for all major independent variables are less than 1 and among those variables of interest, change of quota volume and standard deviation of sunspot index have relatively large elasticities across models.

Figure 3.3.b to Figure 3.3.f plot estimated coefficients on monthly dummies from alternative models respectively. Correlation among seasonality estimated from different models is reported in Table 3.6. Here both VP^{TornM} (M Het measure of price risk), VP^{TornN} (Naïve measure of price risk), and VP^{TornSN} (aggregate price risk measured by Naïve model based on Tornqvist price risk index across commodities) models show similar seasonality pattern as VP^{TornG} model.

Modeling comparisons using two subsets of explanatory variables for VP^{TornG} model are reported in Table 3.7. Dropping monthly dummies has little impact on R-square and the value of the Log of Likelihood Function.

3.5.3 A Comparison of Models using Two-Step and Simple Measures of Aggregate Price Risk

This thesis has argued that aggregate price risk should be measured by a two-step approach: first estimate price variances and covariances for individual commodities (most typically by a multivariate GARCH), and then aggregate these price variances and covariances using an extension of index number theory. The aggregate price risk index VP^{TornG} follows this approach, using a Tornqvist-like index number procedure. This approach avoids serious errors due to contemporaneous

18 The elasticity at the means is the point estimates of the coefficients scaled by the mean of the dependent variable divided by the mean of the regressor; the formula to calculating the elasticity at means is coefficient on X * Mean(X) / Mean(Y).

aggregation of GARCH models and also applies a theoretically correct index number approach to aggregate price risk. In contrast, the standard approach has been used to aggregate price and then estimate the variance of the aggregate price index, e.g. by estimating a univariate GARCH of aggregate price, such as a Tornqvist price index. VP^{TornSG} follows this approach. This approach has been implemented in the literature about aggregate risk, e.g. econometric literature explaining volatility of aggregate stock market returns in terms of economic fundamentals.

However there have been no empirical comparisons of these two approaches in explaining price risk. This study now conducts the first such comparison. Table 3.8.a-c conducts this comparison, using VP^{TornG} and VP^{TornSG}. Table 3.8.a compares explanatory models based on these two alternative measures of aggregate price risk, using common independent variables and lags, which are the union of all variables and lags in Table 3.4 for models using VP^{TornG} and VP^{TornSG}. R-square is 0.78 for the model explaining VP^{TornG} but only 0.23 for the model explaining VP^{TornSG}. Although these results are suggestive, R-square does not provide a clear comparison since the two models have different dependent variables.

A more appropriate approach is to compare values of the likelihood function for the alternative models. Log of likelihood function (LL) is 1510 for the model explaining VP^{TornG} but only 972 for the model explaining VP^{TornSG}. Such a comparison provides a more suitable criterion for model selection and favors the more theoretically correct approach using VP^{TornG}.[19]

One possible explanation for the difference in estimated LL is simply that VP^{TornG} is more highly autocorrelated than VP^{TornSG}, so Table 3.8.b drops lag of price risk from both models. This does not substantially change results: LL is 1395 and 960

[19] There is no need to adopt (e.g.) an Akaike Information Criterion (AIC) since both models have identical explanatory variables and lags.

for the models explaining VP^{TornG} and VP^{TornSG}, respectively.

Finally, we are primarily concerned with how well policy variables (not monthly dummies) are related to risk, so Table 3.8.c drops both lag of price risk and monthly dummies from both models. Again this does not substantially change results: LL is 1390 and 950 for the models explaining VP^{TornG} and VP^{TornSG}, respectively.

In sum, using value of likelihood function as a criteria for model selection, models based on VP^{TornG} provide a better fit and are selected over models based on VP^{TornSG}. This is the first empirical comparison of the two approaches, and results conform to theory.

The above comparison was based on GARCH estimation. Table 3.9.a-c provide a similar comparison of the standard and more theoretically correct approach based on M Het (Multiplicative Heteroskedasticity) estimation. Again the more theoretically correct approach is selected, but the differences in likelihood functions are less dramatic than for GARCH estimation. This may well reflect that errors in contemporaneous aggregation are more severe for GARCH models than for M Het models.

Then Tables 3.10.a-c provide similar comparisons of the two approaches based on naïve estimates of price risk. Here likelihood values are actually higher for the simpler approach. This may largely reflect that the naïve estimates of risk are not based on econometric estimation and hence the simple naïve approach does not involve misspecification of econometric models.

Finally, it is interesting to compare models based on GARCH and M Het. Tables 3.11.a-c compare models with two stage aggregation of risk and GARCH versus M Het estimation, e.g. VP^{TornG} versus VP^{TornM}. In all three tables the log of likelihood function is higher for VP^{TornG} than for VP^{TornM}. So the model with GARCH estimation is selected over the model with M Het estimation.

3.6 Conclusion

This study examines key factors that might influence aggregate price volatility for major grains. This study suggests that infrastructure improvment helps reduce grain price volatility, and that volatility of foreign exchange rate, variation of sun activities and participation in international trade contribute to price risk of major grains. Government policies like reducing authority over the control of grain in 1991-92 and implementation of Rice Bag responsibility system in 1995 apparently help stabilize grain price volatility, while previously existing grain quota policy apparently makes prices more volatile. Results also suggest there is strong seasonality pattern on aggregate price risk, which is stronger during planting and sowing season while weaker during harvest season. Finally, comparisons of results across models suggest that it is important to aggregate price risk properly. Models based on a Tornqvist-type index of aggregate risk have a better fit than models based on a simple univariate GARCH for aggregate price.

If data is available, future research could be improved as follows. First of all, the study could consider more explanatory variables. For instance, China's grain stock volume may buffer between domestic supply and demand and then reduce price variation. Several studies consider the potential impact of energy prices on commodity prices. Growth of the middle classes in China may increase price on the supply side either by increasing demand directly or indirectly via increased feed for live stocks. Secondly, in this study, some annual explanatory factors tested (such as income per capita, average input cost, grain import), were not statistically significant, and this may reflect data problems. Additional attention could also be given to modeling panel data to capture risk response variation across regions within China.

CHAPTER FOUR: EXPLAINING PRICE RISK AT DISAGGREGATE LEVEL FOR MAJOR AGRICULTURAL COMMODITIES IN CHINA

Abstract

This study is an extension of the previous two chapters by explaining price risk at a disaggregate level. Price variances and covariances are modeled using both Ordinary Least Squares (OLS) and Seemly Unrelated Regression (SUR) techniques. Results are broadly consistent with the results presented in previous chapters.

Keywords: China's Major Grains, Disaggregate Price Risk, Seemly Unrelated Regression, Ordinary Least Squares

4.1 Introduction

Aggregate price risk indexes of grain portfolio including rice, wheat, corn and soybeans in China are constructed based on price variances and covariances using superlative approaches in Chapter 2, and then are explained by multivariate regression using important economic and non-economic factors in Chapter 3. Since the markets for the main Chinese grain crops (rice, wheat, corn, and soybeans) operate in the similar way and are subject to the same grain policies, reforms, and similar degree of government intervention (Wu and McErlean 2003), it is appropriate to investigate grain price risk at the aggregate level. Given the scale of these four core grains' contribution to China's agricultural economy, it is also important to examine and understand price volatility at the disaggregate level by analyzing individual price variances and covariances.[20] It is well known that the mean level of grain price is

[20] Individual monthly time series of price variances and covariances of rice, wheat, corn, and soybeans are used in constructing the aggregate price risk indexes in Chapter 2.

responsive to changes in variables such as government policies, income, and input cost that shift demand and supply curves in the market. However, what is not known is how those variables influence price risk, at either an aggregate level or disaggregate level. Do key factors that have significant influences on aggregate price volatility also have similar effects at the disaggregate level? Does the impact of marketing factors such as marketing evolution and grain policies on price volatility vary by grain product? What does the seasonal pattern of individual crop price volatility look like? However, little quantitative information is available publicly. This chapter is the first study of these matters.

Most studies of commodity prices have estimated single-equation models (for example, Mastrangelo 2007; Du and Wang 2004). When the single-equation framework is adopted in this study, several equations are estimated separately by (for example) Ordinary Least Squares (OLS) assuming independence among grain price variances and covariances. However, this assumption seems unrealistic, as prices are influenced by common variables on both production and consumption sides. Hence, it is rational to expect that those individual equations are interrelated and the single-equation framework is less efficient than a system approach (Zellner 1962; Dwivedi and Srivastava 1978).

In contract to the single-equation framework, Seemly Unrelated Regression (SUR) method estimates the parameters of a set of N equations jointly by accounting for contemporaneous cross-equation error correlation and allowing the N equations to have different sets of explanatory variables. Moon and Perron (2006) provide a comprehensive theoretical review on the classical SUR model and its’ extension. Greene (1990) illustrates SUR models and associated estimation methods. There are two main motivations for use of SUR. The first is to gain efficiency in estimation by utilizing information across equations. The second important feature of SUR is the capability to impose and test restrictions on parameters across equations. A large amount of literature exists on the application of SUR models in agriculture (for example, Miller 1979; Reed and Riggins 1981; Streeter and Tomek 1992; and Barnes and Shields 1998). However, apparently SUR has not been used to model price risk for multiple commodities. Here equations explaining all price variances and covariances are estimated jointly by SUR. The rationale for applying SUR lies in the fact that those grains (rice, wheat, corn, and soybeans) have a tight relationship in terms of production and consumption in China. Common factors likely to influence price variances and covariances include weather, marketing shocks, and agricultural policies. These may induce correlations between the equations' error terms. This study is the first attempt to quantitatively explore price volatility systematically for core grains in China.

The rest of the Chapter is organized as follows. The first section presents model specification for the analysis of disaggregate price risk of major grains in China. Second, both Ordinary Least Squares (OLS) and Seemingly Unrelated Regression (SUR) techniques are applied to models explaining individual price variances and covariances. The last section concludes with the main findings of the study and suggestions for future research.

4.2 Model Specification

SUR can be summarized as follows. Consider M regression equations

$$y_i = X_i \beta_i + \varepsilon_i \tag{4.1}$$

$i = 1, \ldots, M$ equations with T observations

with contemporaneous covariances $\text{cov}(\varepsilon_{it}, \varepsilon_{jt}) = \sigma_{ij}$.

Stack the M equations as

$$\begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_M \end{bmatrix} = \begin{bmatrix} X_1 & 0 & \cdots & 0 \\ 0 & X_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & X_M \end{bmatrix} \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_M \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \vdots \\ \varepsilon_M \end{bmatrix} \tag{4.2}$$

which can be re-written compactly as $Y = XB + e$

The contemporaneous cross-equation variance and covariance matrix formulation is:

$$\operatorname{var}(\varepsilon) = \begin{bmatrix} \sigma_{11}I & \sigma_{12}I & \cdots & \sigma_{1M}I \\ \sigma_{21}I & \sigma_{22}I & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{M1}I & \cdots & \cdots & \sigma_{MM}I \end{bmatrix}$$

(4.3)

$$= \begin{bmatrix} \sigma_{11}I & \sigma_{12}I & \cdots & \sigma_{1M}I \\ \sigma_{21}I & \sigma_{22}I & \cdots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ \sigma_{M1}I & \cdots & \cdots & \sigma_{MM}I \end{bmatrix} \otimes I_{T\times T}$$

$$= \Sigma \otimes I_{T\times T} = \Psi$$

where Σ is a positive definite symmetric matrix, and $\otimes$ is the Kronecker product and I is an identical matrix (TxT). The assumption of the model is that error terms ε_{it} are independent across time, but may have cross-equation contemporaneous correlations.

The SUR Generalized Least Squares (GLS) estimator of B is given by:

$$\hat{\beta}_{GLS} = (X'\Psi^{-1}X)^{-1}X'\Psi^{-1}Y$$

(4.4)

In equation (4.4) coefficient estimates of an individual equation depend not only on its data but also information from other equations. SUR estimates differ from single-equation OLS estimates if there is contemporaneous covariance (and explanatory variables are not identical across equations), or there are cross-equation restrictions on coefficients. Efficiency gains for SUR depends on magnitudes of the contemporaneous covariances.

The SUR model system for explaining disaggregated price risk consists of ten single equations for rice, wheat, corn and soybeans:

$$VarP_t^r = \beta_0^r + \sum_{i=1}^{m} \beta_t^r VarP_{t-i}^r + \sum_{j=1}^{n} \beta_j^r x_{jt}^r + \sum_{k=1}^{w} \beta_k^r Policy_k^r + \sum_{l=1}^{11} \beta_l^r mnth_l^r + \varepsilon_t^r \qquad (4.5)$$

$$VarP_t^w = \beta_0^w + \sum_{i=1}^{m} \beta_t^w VarP_{t-i}^w + \sum_{j=1}^{n} \beta_j^w x_{jt}^w + \sum_{k=1}^{w} \beta_k^w Policy_k^w + \sum_{l=1}^{11} \beta_l^w mnth_l^w + \varepsilon_t^w \qquad (4.6)$$

$$VarP_t^c = \beta_0^c + \sum_{i=1}^{m} \beta_t^c VarP_{t-i}^c + \sum_{j=1}^{n} \beta_j^c x_{jt}^c + \sum_{k=1}^{w} \beta_k^c Policy_k^c + \sum_{l=1}^{11} \beta_l^c mnth_l^c + \varepsilon_t^c \qquad (4.7)$$

$$VarP_t^s = \beta_0^s + \sum_{i=1}^{m} \beta_t^s VarP_{t-i}^s + \sum_{j=1}^{n} \beta_j^s x_{jt}^s + \sum_{k=1}^{w} \beta_k^s Policy_k^s + \sum_{l=1}^{11} \beta_l^s mnth_l^s + \varepsilon_t^s \qquad (4.8)$$

$$CVarP_t^{rw} = \beta_0^{rw} + \sum_{i=1}^{m} \beta_t^{rw} CVarP_{t-i}^{rw} + \sum_{j=1}^{n} \beta_j^{rw} x_{jt}^{rw} + \sum_{k=1}^{w} \beta_k^{rw} Policy_k^{rw} + \sum_{l=1}^{11} \beta_l^{rw} mnth_l^{rw} + \varepsilon_t^{rw}$$

(4.9)

$$CVarP_t^{rc} = \beta_0^{rc} + \sum_{i=1}^{m} \beta_t^{rc} CVarP_{t-i}^{rc} + \sum_{j=1}^{n} \beta_j^{rc} x_{jt}^{rc} + \sum_{k=1}^{w} \beta_k^{rc} Policy_k^{rc} + \sum_{l=1}^{11} \beta_l^{rc} mnth_l^{rc} + \varepsilon_t^{rc}$$

(4.10

$$CVarP_t^{rs} = \beta_0^{rs} + \sum_{i=1}^{m} \beta_t^{rs} CVarP_{t-i}^{rs} + \sum_{j=1}^{n} \beta_j^{rs} x_{jt}^{rs} + \sum_{k=1}^{w} \beta_k^{rs} Policy_k^{rs} + \sum_{l=1}^{11} \beta_l^{rs} mnth_l^{rs} + \varepsilon_t^{rs}$$

(4.11)

$$CVarP_t^{wc} = \beta_0^{wc} + \sum_{i=1}^{m} \beta_t^{wc} CVarP_{t-i}^{wc} + \sum_{j=1}^{n} \beta_j^{wc} x_{jt}^{wc} + \sum_{k=1}^{w} \beta_k^{wc} Policy_k^{wc} + \sum_{l=1}^{11} \beta_l^{wc} mnth_l^{wc} + \varepsilon_t^{wc}$$

(4.12)

$$CVarP_t^{ws} = \beta_0^{ws} + \sum_{i=1}^{m} \beta_t^{ws} CVarP_{t-i}^{ws} + \sum_{j=1}^{n} \beta_j^{ws} x_{jt}^{ws} + \sum_{k=1}^{w} \beta_k^{ws} Policy_k^{ws} + \sum_{l=1}^{11} \beta_l^{ws} mnth_l^{ws} + \varepsilon_t^{ws} \tag{4.13}$$

$$CVarP_t^{cs} = \beta_0^{cs} + \sum_{i=1}^{m} \beta_t^{cs} CVarP_{t-i}^{cs} + \sum_{j=1}^{n} \beta_j^{cs} x_{jt}^{cs} + \sum_{k=1}^{w} \beta_k^{cs} Policy_k^{cs} + \sum_{l=1}^{11} \beta_l^{cs} mnth_l^{cs} + \varepsilon_t^{cs} \tag{4.14}$$

Here superscript r, w, c, s, denotes rice, wheat, corn, and soybeans respectively; $VarP_t^r$ is variance of rice price at time t, $VarP_t^w$ is variance of wheat price, $VarP_t^c$ is variance of corn price, $VarP_t^s$ is variance of soybeans price, $CVarP_t^{rw}$ is covariance of rice price and wheat price, $CVarP_t^{rc}$ is covariance of rice price and corn price, $CVarP_t^{rs}$ is covariance of rice price and soybeans price, $CVarP_t^{wc}$ is covariance of wheat price and corn price, $CVarP_t^{ws}$ is covariance of wheat price and soybean price, $CVarP_t^{cs}$ is covariance of corn and soybeans prices, $VarP_{t-i}$ or $CVarP_{t-i}$ is the lagged dependent variables for variance and covariance respectively; x_{jt} represents candidate explanatory variables in the format of either level, change, or variance; $Policy_k$ stands for dummy variable representing the impact of implementation of major policy; $mnth_l$ denotes monthly dummy; β s are regression coefficients to be estimated; and ε_t is the error term for time t. These ten regression equations are estimated separately by OLS and jointly by SUR.

4.3 Results

The results are presented in several sections. First, regression models are estimated separately equation-by-equation using OLS to achieve the best specification for individual price variance and covariance equations. Then, SUR is used to estimate the 10 equations simultaneously. The estimation results obtained from both approaches are discussed and compared. Furthermore, parameter restrictions are tested across equations and the results are compared with results for aggregate risk model in Chapter 3.

Data used in this study are adapted from previous Chapter 2 and Chapter 3. The analysis is from January 1987 to December 2007 at the monthly level. Dependent variables are monthly price variances and covariances for rice, corn, wheat, and soybeans, which are calculated by superlative two-step approach and univariate GARCH model[21] in Chapter 2. Explanatory variables include economic and non-economic variables described in detail in Chapter 3. Statistical analyses are undertaken using the software Shazam and Eviews.

The correlation coefficients among price variances and covariances are reported in Table 4.1. The results show that individual price variances and covariances are positively correlated and half of correlation coefficients are great than 0.5. This implies that all price variances and covariances move together on average, however the degree of movement varies across commodities. For example, the correlation between variance of rice price ($VarP^r$) and variance of wheat price ($VarP^w$) is 0.39 while the correlation between variance of wheat price ($VarP^w$) and variance of corn price ($VarP^c$) is only 0.09.

First, both Augmented Dickey- Fuller (ADF) and Phillips-Perron unit root tests are implemented to test stationary of monthly price variance and covariance time

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[21] Price variance and covariance measured by superlative two-step approach and univariate GARCH model are chosen for this disaggregate level analysis for several reasons: GARCH model has been popular to deal with time series data; GARCH model fits the price mean and second moment well according to Chapter 2; secondly, aggregate price risk indexes constructed by GARCH model has better statistical performance according to Chapter 3. The superlative two-step approach measuring time varying price variances and covariances dates back to Bollerslev (1990), and is extended by Engle and Sheppard (2001), and recently revisited by Engle (2002)

series. Test results are presented in Table 4.2.a and Table 4.2.b. Both unit root tests reject the null hypothesis of unit root in the level for all dependent variables except for price covariance between corn and soybeans[22]. For the covariance of corn price and soybeans price model, both dependent variable and independent variables are specified as a first difference.

The study then conducts the correlogram plot to find the appropriate lag for each dependent variable based on autocorrelation function (ACF) and partial autocorrelation function (PACF) plots. As shown in Table 4.3.a to Table 4.3.j, most of price variances and covariances display the classical character for AR process with the autocorrelations (ACF) decaying fast across lags, and the partial correlation coefficient (PACF) becomes zero after lag 1 or 2.

Initially OLS is applied to estimate equations (4.5) to (4.14) separately. The model describes individual price variances and covariances as a function of potential explanatory variables that have been defined and discussed in detail in Chapter 3. Explanatory variables include lagged dependent variables, infrastructure development index, major agricultural marketing policies, change of grain quota volume, change of international trade participation index, standard deviation of sunspot activity index, and change of income per capita. OLS estimation results are reported in Tables 4.5.a to 4.5.e.

The specification of lagged price risk in each of the ten price risk equations by itself implies differences in explanatory variables across equations, so SUR results are not identical to OLS. Gains in efficiency for SUR depend on magnitudes of contemporaneous covariances of disturbances. So it is critical to test if these covariances are statistically significant. First, the correlation coefficients between the

[22] KPSS test is also applied to confirm the unit root problem for the covariance of corn price and soybeans price. KPSS test results indicate that the null hypothesis of stationarity is rejected at conventional levels of significance. So there is evidence of unit root for this time series.

OLS residuals from different equations are checked. The correlation matrix, as shown in Table 4.4, indicates that residuals for several equations are moderately or highly interrelated. For example, residuals for variance of soybeans price ($VarP^s$) and variance of wheat price ($VarP^w$) show a correlation coefficient 0.70, and residuals for covariance of wheat and corn price ($CVarP^{wc}$) and covariance of rice and corn price ($CVarP^{rc}$) show a correlation coefficient 0.57. Second, the LaGrange-Multiplier test[23] suggested by Breusch Pagan (1980) is used to test for contemporaneous covariance. The null hypothesis is about the absence of no contemporaneous correlation of errors across equations. The calculated Chi-square with 45 D.F. equals 1743.5 (p-value=0.0000). So the null hypothesis is rejected at any reasonable level of significance.

Tables 4.5.a to 4.5.e summarize SUR as well as OLS estimates for all ten price risk models. Durbin-H statistics generally imply that zero autocorrelation is not rejected.[24] OLS and SUR methods yield close results in terms of signs as well as magnitudes. Estimated standard errors of coefficients generally are lower using SUR than OLS, as expected.

Eight out of ten price risk models show reasonable goodness of fit, with R-squares varying from 0.60 to 0.90 (the equation for covariance of corn price and soybeans price ($CVarP^{cs}$) has a R-square 0.18). The estimated coefficient of most explanatory variables of interest show expected signs consistently across individual price risk models. Moreover general insights obtained from this disaggregate analysis are similar to those from the aggregate level analysis in Chapter 3. The impact of

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[23] Breusch and Pagan's (1980) LaGrange-Multiplier test is $\lambda_{LM} = T\sum_{i=2}^{n}\sum_{j=1}^{i-1} r_{ij}^2$,where T is the sample size, i is number of equationa in the SUR system, r_{ij}^2 denotes squared correlation.

[24] R-square and adjusted R-square are not useful for individual equations within an SUR system since all equations are estimated simultaneously.

infrastructure development index is negative, which implies that the improvement in marketing efficiency measured by domestic physical infrastructure over time helps to stabilize grain prices. Change in the quota volume, variance of effective nominal exchange rate, variation of international trade participation degree, and change in income per capita have positive signs as expected, which suggests that an increase in these variables generally leads to increased price volatility. Standard deviation of sunspot index shows a positive relationship with price risk, although the coefficient is insignificant. Estimated coefficients for policy dummies (representing nationwide policies that lessen the government's authority over the control of grain in 1991-92, implementation of Rice Bag responsibility system in 1995, and the execution of a new grain marketing and stock-holding policy in April 1998) generally have expected signs but not always statistically significant.

Monthly dummies are included in each price risk equation to capture potential seasonality effects over the course of a year. In the case of price variances, almost all monthly dummies are statistically significant, indicating clear seasonality. However the pattern seems distinct due to the unique seasonal growing cycle of each crop. Figure 4.1.a to Figure 4.1.d plot monthly seasonality pattern for price variances. In general, price variations are observed higher during planting season which is associated with uncertainty on weather and markets. The rice price variance ($VarP^r$) peaks in April and July which is the main season for planting single crop rice and early double crop rice respectively in China. The soybeans price variance ($VarP^s$) is slightly higher from March to May, which is the main season for sowing soybeans in China. The seasonality pattern of price covarainces are less clear in terms of biological cycle of crop production. Monthly dummies are not statistically significant in most price covariance models. However correlations between seasonal patterns from covariance models are high, which suggests that price coariances move together on average throughout the year.

Elasticities at the mean for key explanatory variables are reported in Table 4.7. The impact of infrastructure development on disaggregate level grain price risk varies significantly across models in terms of magnitude of elasticities. Results suggest that over the past 30 years, the improvement in marketing efficiency (measured by domestic physical infrastructure including domestic logistics) has especially reduced risk for the price of rice since the variance of the price of rice ($VarP^r$) has the largest negative elasticity with respect to infrastructure development index. This is interesting since rice is particularly important in China's agricultural economy: rice provides almost half of China's grain production according to National Bureau of Statistics China. In contrast, infrastructure development does not have a statistically significant impact on variance of the price of wheat. Another key finding is that international trade participation is statistically significant in most price risk models, but the magnitude of the coefficient is relatively small compared with other explanatory variables. Since the open-door policy in later 1970s and especially China's accession in World Trade Organization (WTO) in 2002, the international trade volume of grains has grown rapidly. As the world's leading importer and exporter of grain, China's participation in international market has had substantial influence on domestic grain market and hence grain price volatility in different ways. However the low ratio between international trade volumes to domestic grain production along with the Chinese government's grain policies interventions make the impact of trade liberalization on price volatility smaller than expected. Sunspot activities impact price variances and covariances similarly. Price variances are more sensitive to change of procurement quota than price covariances. Furthermore, when the elasticities obtained from disaggregate models are compared to those obtained from the aggregate model in Chapter 3, on average, disaggregate models have larger elasticities.

As mentioned earlier in this chapter, one of the advantages of using SUR is to test for the equality of coefficients across models. The hypothesis of slope coefficient homogeneity is performed for each key variable separately. F-statistic test results are summarized in Table 4.8. The null hypothesis of slope coefficient homogeneity is rejected for infrastructure development, change of quota, and international trade participation at any conventional level; on the other hand, the null hypothesis of slope coefficient homogeneity is not rejected (at any conventional significance level) for effective exchange rate, sunspot activity, and all policy dummies.

4.4 Conclusion

This study explains price risk at a disaggregate level for major grains (rice, wheat, corn, and soybeans) in China. Empirical evidence suggests that price variances and covariances are influenced by key variables including infrastructure development, change of grain quota, variation in effective exchange rate, variance of sun activities, and international trade. Individual price risk also shows significant AR process pattern as well as seasonality pattern over the course of a year. OLS and SUR estimation methods are applied and their findings are compared. Estimated standard errors of coefficients generally are smaller for SUR than for OLS, as anticipated.

Here we mention several possible improvements for future study. First, if data is available including crop specific explanatory variables such as government policies related to a specific product or crop level input or cost. This may lead to more elaborate crop level insights. Second, the findings of this study are still preliminary due to the complexity of China’s grain marketing and trade evolution.

CHAPTER FIVE: GENERAL CONCLUSION

This research compares alternative approaches for measuring aggregate price risk over Chinese major grains. The superlative aggregate price risk index is emphasized since it uses index number theory appropriately in incorporating both variances and covariances of price risk. High correlations between aggregate price risk indexes constructed using different outcome quantity indexes are observed. Using the same output quantity index (Tornqvist-type), aggregate price risk indexes are compared across approaches to measuring price risk. The empirical results obtained here reveal positive correlation across alternative approaches. For GARCH and M Het models, correlation between superlative aggregate price risk indexes and simple univariate measures are low. Thus the theoretically superior measure of aggregate price risk is also quite different from the simple measure, at least with this data set. As a pioneer study this paper has important implications for quantifying aggregate price risk over commodities in the case of Chinese major grains. Many research issues still remain.

This study examines key factors that might influence aggregate price volatility for major grains. This study suggests that infrastructure development helps reduce grain price volatility, and that volatility of foreign exchange rate, variation of sun activities and participation in international trade contribute to price risk of major grains. Government policies like reducing authority over the control of grain in 1991-92 and implementation of Rice Bag responsibility system in 1995 apparently help stabilize grain price volatility, while previously existing grain quota policy apparently makes prices more volatile. Results also suggest there is strong seasonality pattern on aggregate price risk, which is stronger during planting and sowing season while weaker during harvest season.

Moreover, comparisons of results across models explaining risk suggest that it is important to aggregate price risk properly. Models based on a Tornqvist-type index of aggregate risk have a better fit than models based on a simple univariate GARCH for aggregate price. Other econometric studies explaining risk are limited to models of aggregate volatility of returns in stock markets in terms of economic variables, and these studies employ a common but theoretically incorrect method for aggregating risk. So the current study is unique in the literature.

This study also explains price risk at a disaggregate level for major grains (rice, wheat, corn, and soybeans) in China. Empirical evidence suggests that price variances and covariances are influenced by key variables including infrastructure development, change of grain quota, variation in effective exchange rate, variance of sun activities, and international trade. Individual price risk also shows significant AR process pattern as well as seasonality pattern over the course of a year. OLS and SUR estimation methods are applied and their findings are compared. Estimated standard errors of coefficients generally are smaller for SUR than for OLS, as anticipated.

Here we mention several possible improvements for future study. Further research could consider relaxing the assumption of constant conditional correlation in the two-step approach to constructing conditional variance and covariance. Changes of price covariance over time may come from both dynamic correlation (Engle and Sheppard 2001; Engle 2002) as well as time varying standard errors. Also this research could expand the scope by incorporating price risk of livestocks such as hogs, which heavily rely on major grains as input in China so price variation of major livestocks may be highly correlated with major grains in China. If data is available, this study could consider more explanatory variables such as China’s grain stock volume, energy prices on commodity prices, and growth of the middle classes in

China. In this study, some annual explanatory factors tested (such as income per capita, average input cost, grain import), were not statistically significant, and this may reflect data problems. Additional attention could also be given to modeling panel data to capture risk response variation across regions within China. If data is available, possible improvement for disaggregate level analysis is to include crop specific explanatory variables such as government policies related to a specific product or crop level input or cost. This may lead to more elaborate crop level insights. Lastly, the findings of this study are still preliminary due to the complexity of China's grain marketing and trade evolution.

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APPENDIX ONE

Table 2.1. Descriptive Statistics of Monthly Commodities Prices (Yuan/Kg), 1987-2007

Variable	Mean	Minimum	Maximum	Standard Deviation
P^{rice}	1.22	0.55	1.98	0.41
P^{wheat}	1.16	0.59	1.80	0.33
P^{corn}	1.02	0.48	1.67	0.32
$P^{soybeans}$	2.52	1.01	4.88	0.80

Notes: P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.2. Correlations among Monthly Commodities Prices, 1987-2007

	P^{rice}	P^{wheat}	P^{corn}
P^{wheat}	0.98		
P^{corn}	0.96	0.95	
$P^{soybeans}$	0.86	0.84	0.87

Notes: P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.3 Descriptive Statistics of Annual Commodities Quantity (10,000 tons), 1987-2007

Variable	Mean	Minimum	Maximum	Standard Deviation
Y^{rice}	18,303	18,257	20,073	16,066
Y^{wheat}	9,984	9,930	12,329	8,543
Y^{corn}	11,228	11,199	15,230	7,735
$Y^{soybeans}$	1,392	1,473	1,740	971

Notes: Y^{rice} denotes rice quantity, Y^{wheat} denotes wheat quantity, Y^{corn} denotes corn quantity, and $Y^{soybeans}$ denotes soybeans quantity.

Table 2.4 Heteroskedasticity Test for Monthly Commodity Prices, 1987-2007

Test	P^{rice}		P^{wheat}		P^{corn}		$P^{soybean}$	
	Chi-square Test Statistic	p-value	Chi-square Test Statistic	p-value	Chi-square Test Statistic	p-value	Chi-square Test Statistic	p-value
Harvey	-398.729	0.00000	-333.345	0.00000	-588.335	0.00000	-375.382	0.00000
Glejser	24.723	0.00000	-1.774	0.00000	47.427	0.00000	59.763	0.00000
ARCH		0.0678		0.0007		0.01701		0.00193
White(B-P-G)	53.752	0.00000	25.420	0.00012	51.192	0.00000	130.477	0.00000

Notes: P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.5 Results of GARCH (1,1) Model for Grain Prices

Coefficient	P^{rice}	P^{wheat}	P^{corn}	$P^{soybeans}$
Mean Equation:				
Constant	0.0068	0.0060	0.0036	0.0064
	(1.02)	(1.09)	(0.70)	(0.56)
Lag 1	1.17***	1.38***	1.29***	1.08***
	(24.62)	(19.20)	(18.22)	(14.71)
Lag 2		-0.35***	-0.13	0.093
		(-4.29)	(-1.11)	(1.01)
Lag 3	-0.11*		-0.16**	
	(-1.72)		(-2.24)	
Lag 4				
Lag 5				-0.18***
				(-4.57)
Lag 6	-0.069**	-0.036*		
	(1.02)	(-1.72)		
Variance Equation:				
α_0	0.00015**	0.00016**	0.000022	0.000028
	(2.10)	(2.41)	(1.41)	(0.67)
α_1	0.17***	0.39***	0.10040**	0.15***
	(2.62)	(3.25)	(2.52)	(3.72)
φ_1	0.75***	0.52***	0.89***	0.89***
	(9.15)	(4.49)	(20.03)	(31.89)

Notes: t-ratio is reported in parenthesis.
*** denotes 1% significance level, ** 5% significance level, * 10% significant level.
P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.6 Results of M Het Model for Grain Prices

Coefficient	P^{rice}	P^{wheat}	P^{corn}	$P^{soybeans}$
Mean Equation:				
Constant	0.011*	0.013***		
	(1.71)	(2.01)		
Lag 1	1.10***	1.29***	1.29***	1.13***
	(54.64)	(20.41)	(20.49)	(44.65)
Lag 2		-0.17**	-0.069	
		(-2.01)	(-0.65)	
Lag 3			-0.22***	
			(-3.47)	
Lag 4		-0.13		
		(-3.35)		
Lag 5				-0.13***
				(-4.99)
Lag 6	-0.11***			
	(-5.72)			
Variance Equation:				
Constant	-7.84***	-8.11***	-9.90***	-8.51***
	(-26.88)	(-24.10)	(-32.28)	(-27.04)
Lag 1	5.17***		3.08*	1.22***
	(6.40)		(1.74)	(10.23)
Lag 2		2.64***		
		(2.889)		
Lag 3			-3.71	
			(-1.26)	
Lag 4				
Lag 5	-4.25***		3.32*	
	(-5.29)		(1.87)	
Lag 6		-1.77**		
		(-2.00)		

Notes: t-ratio is reported in parenthesis.
*** denotes 1% significance level, ** 5% significance level, * 10% significant level.
P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.7 Constant Conditional Correlation Obtained from GARCH models of Commodity Price

	P^{rice}	P^{wheat}	P^{corn}	$P^{soybeans}$
P^{rice}	1			
P^{wheat}	0.50	1		
P^{corn}	0.23	0.23	1	
$P^{soybeans}$	0.39	0.34	0.29	1

Notes: P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.8 Constant Conditional Correlation obtained from M Het models of Commodity Price

	P^{rice}	P^{wheat}	P^{corn}	$P^{soybeans}$
P^{rice}	1			
P^{wheat}	0.48	1		
P^{corn}	0.24	0.24	1	
$P^{soybeans}$	0.37	0.35	0.36	1

Notes: P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.

Table 2.9 Correlations between Price Risk Indexes based on Different Output Quantity Index, in the case of GARCH Estimation

	VP^{TornG}	VP^{LaspG}
$VP^{FisherG}$	0.99856	0.99954
VP^{LaspG}	0.99711	

Notes: VP^{TornG}, $VP^{FisherG}$, and VP^{LaspG} denote aggregate price risk index in which risk of individual prices is specified by GARCH model and based on Tornqvist quantity index, Fisher quantity index, and Laspeyres quantity index respectively.

Table 2.10 Correlations between Price Risk Indexes across Risk Estimation Approaches (GARCH, M Het, Naïve), in the Case of Tornqvist Output Index

	VP^{TornN}	VP^{TornG}	VP^{TornM}
VP^{TornN}	1		
VP^{TornG}	0.64	1	
VP^{TornM}	0.39	0.24	1

Notes: VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively

Table 2.11 Correlations between Price Risk Indexes: Economic Index Number vs. Simple Univariate Approach

VP^{TornG} vs. VP^{TornSG}	0.37
VP^{TornM} vs. VP^{TornSM}	0.31
VP^{TornN} vs. VP^{TornSN}	0.89

Notes: VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and Naïve approach based on Tornqvist price index over commodities respectively.

Table 3.1 Unit Root Tests for Monthly Time Series Variables

Variable	ADF	PP	Ays.Critical Value(10%)
VP^{TornG}	-8.11	-8.10	-3.13
VP^{TornM}	-4.12	-7.05	-3.13
VP^{TornN}	-3.88	-6.79	-3.13
VP^{TornSG}	-4.82	-15.59	-3.13
VP^{TornSM}	-3.94	-13.80	-3.13
VP^{TornSN}	-3.59	-6.80	-3.13
Variance of Effective Exchange Rate	-5.87	-14.35	-3.13
Standard Deviation of Sunspot Index	-1.96	-8.47	-3.13

Notes: Trend and intercept are included in test equation ;
MacKinnon Critical Values for rejection of hypothesis of a unit root is listed in the table;
ADF denotes Augmented Dickey-Fuller Test Statistics and PP denotes Phillips-Perron Test Statistics;
VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and Naïve approach based on Tornqvist price index over commodities respectively.

Table 3.2 Correlation Matrix Among Explanatory Variables

	Infrastructure development Index	Change Quota	Variance of Effective Exchange Rate	Degree of International Trade Participation	Standard Deviation of Sunspot Rate	Percentage of Disaster Area	Change Input
Infrastructure Development Index	1						
Change Quota	-0.32	1					
Variance of Effective Exchange Rate	-0.09	0.19	1				
Degree of International Trade Participation	0.03	-0.21	-0.04	1			
Standard Deviation of Sunspot Rate	-0.41	-0.23	0.11	0.19	1		
Percentage of Disaster Area	0.23	-0.14	0.00	0.60	0.03	1	
Change Input	-0.27	0.69	0.11	-0.25	-0.18	-0.35	1

Table 3.3.a Correlogram of VP^{TornG}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.757	0.757	142.80	0.000
.|**** |	.|. |	2	0.598	0.057	232.18	0.000
.|**** |	.|* |	3	0.505	0.081	296.15	0.000
.|*** |	.|. |	4	0.413	-0.015	339.10	0.000
.|** |	.|. |	5	0.323	-0.032	365.53	0.000
.|** |	.|. |	6	0.255	-0.006	382.02	0.000
.|* |	*|. |	7	0.173	-0.071	389.63	0.000
.|* |	.|. |	8	0.132	0.034	394.09	0.000
.|* |	.|* |	9	0.136	0.085	398.86	0.000
.|* |	.|. |	10	0.133	0.026	403.45	0.000
.|* |	.|* |	11	0.153	0.080	409.52	0.000
.|* |	.|. |	12	0.167	0.024	416.83	0.000

Notes: VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model.

Table 3.3.b: Correlogram of VP^{TornM}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.668	0.668	111.15	0.000
.|** |	**|. |	2	0.331	-0.209	138.47	0.000
.|** |	.|** |	3	0.266	0.263	156.29	0.000
.|** |	.|. |	4	0.242	-0.050	171.00	0.000
.|* |	.|. |	5	0.150	-0.024	176.68	0.000
.|. |	.|. |	6	0.063	-0.033	177.68	0.000
.|. |	.|. |	7	0.003	-0.059	177.69	0.000
.|. |	.|* |	8	0.054	0.162	178.45	0.000
.|* |	.|. |	9	0.111	-0.002	181.61	0.000
.|* |	.|. |	10	0.110	0.056	184.76	0.000
.|* |	.|. |	11	0.119	0.057	188.45	0.000
.|* |	.|. |	12	0.124	-0.027	192.43	0.000

Notes: VP^{TornM} denotes aggregate Tornqvist-tepe price risk index in which risk of individual prices is specified by M Het model.

Table 3.3.c: Correlogram of VP^{TornN}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.699	0.699	121.50	0.000
.|*** |	*|. |	2	0.444	-0.087	170.69	0.000
.|** |	.|* |	3	0.324	0.094	197.00	0.000
.|** |	.|* |	4	0.303	0.117	220.11	0.000
.|* |	*|. |	5	0.212	-0.111	231.51	0.000
.|* |	.|. |	6	0.133	0.009	236.01	0.000
.|. |	*|. |	7	0.014	-0.152	236.07	0.000
.|. |	.|. |	8	-0.020	0.044	236.16	0.000
.|. |	.|. |	9	0.010	0.073	236.19	0.000
.|. |	.|. |	10	0.009	-0.052	236.21	0.000
.|. |	.|* |	11	0.015	0.092	236.27	0.000
.|. |	*|. |	12	-0.028	-0.119	236.48	0.000

Notes: VP^{TornN} denotes aggregate Tornqvist-tepe price risk index in which risk of individual prices is specified by Naïve approach.

Table 3.3.d: Correlogram of VP^{TornSG}

Sample: 1987M07 2007M12

Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|. |	.|. |	1	0.005	0.005	0.0053	0.942
.|. |	.|. |	2	0.013	0.013	0.0447	0.978
.|. |	.|. |	3	0.067	0.067	1.1734	0.759
.|** |	.|** |	4	0.288	0.289	22.135	0.000
.|. |	.|. |	5	0.055	0.063	22.908	0.000
.|. |	.|. |	6	0.038	0.033	23.275	0.001
.|. |	.|. |	7	0.070	0.036	24.518	0.001
.|. |	.|. |	8	0.056	-0.036	25.312	0.001
.|. |	.|. |	9	0.035	-0.003	25.622	0.002
.|. |	.|. |	10	0.005	-0.026	25.630	0.004
.|. |	.|. |	11	0.018	-0.020	25.719	0.007
.|. |	.|. |	12	0.064	0.053	26.775	0.008

Notes: VP^{TornSG} denotes the aggregate price risk obtained from univariate GARCH model based on Tornqvist price index over commodities.

Table 3.3.e: Correlogram of VP^{TornSM}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|* |	.|* |	1	0.119	0.119	3.4994	0.061
.|* |	.|* |	2	0.142	0.130	8.5720	0.014
.|* |	.|* |	3	0.123	0.095	12.349	0.006
.|** |	.|** |	4	0.319	0.291	38.032	0.000
.|* |	.|* |	5	0.142	0.076	43.126	0.000
.|* |	.|* |	6	0.159	0.080	49.533	0.000
.|. |	*|. |	7	-0.024	-0.127	49.676	0.000
.|. |	*|. |	8	0.007	-0.134	49.689	0.000
.|. |	.|. |	9	0.056	-0.015	50.506	0.000
.|. |	*|. |	10	-0.017	-0.092	50.578	0.000
.|. |	.|* |	11	0.053	0.103	51.317	0.000
.|. |	.|. |	12	-0.016	0.032	51.387	0.000

Notes: VP^{TornSM} denotes the aggregate price risk obtained from univariate M Het model based on Tornqvist price index over commodities.

Table 3.3.f: Correlogram of VP^{TornSN}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.678	0.678	114.52	0.000
.|*** |	.|. |	2	0.466	0.010	168.71	0.000
.|*** |	.|* |	3	0.364	0.082	201.98	0.000
.|*** |	.|** |	4	0.443	0.306	251.47	0.000
.|*** |	*|. |	5	0.355	-0.144	283.37	0.000
.|** |	.|. |	6	0.240	-0.053	297.98	0.000
.|* |	*|. |	7	0.095	-0.122	300.27	0.000
.|. |	*|. |	8	0.048	-0.076	300.85	0.000
.|. |	.|. |	9	0.045	0.044	301.36	0.000
.|. |	.|. |	10	0.028	-0.027	301.56	0.000
.|. |	.|* |	11	0.023	0.105	301.69	0.000
.|. |	.|. |	12	-0.023	-0.044	301.83	0.000

Notes: VP^{TornSN} denotes the aggregate price risk obtained from simple Naïve approach based on Tornqvist price index over commodities.

Table 3.4: Time Series Multivariate Model to Explain Aggregated Price Risk Indexes

Regressor \ Dependent	VP^{TornG}	VP^{TornM}	VP^{TornN}	VP^{TornSG}	VP^{TornSM}	VP^{TornSN}
Lag 1 of Dependent	0.68***	0.88***	0.65***			0.63***
	(18.74)	(13.88)	(13.93)			(12.85)
Lag 2 of Dependent		-0.44***				
		(-5.49)				
Lag 3 of Dependent		0.32***				
		(5.23)				
Lag 4 of Dependent				0.30***	0.31***	
				(4.80)	(5.21)	
Lag 5 of Dependent					0.15**	
					(2.42)	
Lag 6 of Dependent			-0.08			
			(-1.53)			
Infrastructure Development Index	-0.00000027***	-0.0000000012***	-0.0000000005		-0.0000000002	-0.00000000034
	(-3.01)	(-3.77)	(-0.18)		(-0.19)	(-0.65)
Change Quota	0.000000011*	0.000000015	0.00000052***	0.00000013	0.00000019***	0.00000011***
	(1.96)	(0.78)	(2.84)	(2.90)	(3.03)	(3.25)
Variance of Effective Exchange Rate	0.0000013***	0.0000012	0.000055***		0.0000165***	0.0000077***
	(4.49)	(1.09)	(5.48)		(4.53)	(4.06)
Standard Deviation of Sunspot Index	0.0000049		0.00015			
	(1.48)		(1.56)			
Degree of International Trade Participation	0.0041**	0.022***	0.15**	0.043**	0.087***	0.044***
	(2.02)	(2.78)	(2.09)	(2.39)	(3.45)	(3.39)
D9192	-0.00014	-0.00024	-0.0084**	-0.0017*	-0.0020	-0.0012
	(-1.10)	(-0.54)	(-2.01)	(-1.68)	(-1.36)	(-1.62)
D95	-0.00025	-0.00035	0.0024	-0.0014	-0.0029	-0.00037
	(-1.52)	(-0.56)	(0.39)	(-0.93)	(-1.34)	(-0.34)
D9899	0.00011	0.00040	0.0013		0.00045	0.000075
	(0.89)	(0.88)	(0.33)		(0.32)	(0.10)
Month_Jan	-0.00016	0.0014**	-0.0018	-0.0013	-0.0026	-0.0016
	(-0.92)	(2.20)	(-0.32)	(-0.85)	(-1.25)	(-1.49)

Table 3.4: Time Series Multivariate Model to Explain Aggregated Price Risk Indexes (Continued)

Month_Feb	-0.00027	0.00049	-0.015**	-0.00094	-0.0030	-0.0027**
	(-1.61)	(0.75)	(-2.59)	(-0.62)	(-1.45)	(-2.51)
Month_Mar	-0.00035**	0.00094	-0.020***	0.00027	0.00071	-0.0038***
	(-2.07)	(1.45)	(-3.47)	(0.18)	(0.34)	(-3.48)
Month_Apr	0.000063	0.0014**	-0.0041	-0.0017	-0.0037*	-0.00083
	(0.37)	(2.20)	(-0.73)	(-1.13)	(-1.74)	(-0.77)
Month_May	-0.00027	0.00050	-0.013**	-0.0011	-0.0028	-0.0027**
	(-1.60)	(0.76)	(-2.22)	(-0.73)	(-1.33)	(-2.46)
Month_Jun	-0.00032*	0.00079	-0.014**	0.0028*	-0.00090	-0.0029***
	(-1.86)	(1.21)	(-2.42)	(1.84)	(-0.42)	(-2.69)
Month_Jul	-0.000050	0.00058	-0.011**	-0.0017	-0.0039*	-0.0024**
	(-0.29)	(0.8636)	(-1.98)	(-1.16)	(-1.85)	(-2.22)
Month_Aug	-0.00054***	-0.00052	-0.016***	-0.00061	-0.0036*	-0.0028***
	(-3.17)	(-0.7998)	(-2.79)	(-0.41)	(-1.75)	(-2.63)
Month_Sep	-0.00040**	-0.00037	-0.016***	0.00022	-0.0011	-0.0032***
	(-2.39)	(-0.58)	(-2.87)	(0.15)	(-0.53)	(-2.99)
Month_Oct	-0.00028*	0.00015	-0.011*	-0.0018	-0.0039*	-0.0023**
	(-1.69)	(0.23)	(-1.91)	(-1.21)	(-1.88)	(-2.16)
Month_Nov	-0.00042**	-0.00072	-0.014**	0.0029**	0.0027	-0.0029***
	(-2.55)	(-1.13)	(-2.48)	(2.00)	(1.32)	(-2.688)
Constant	0.0010***	0.0015**	0.014***	0.0017	0.0027*	0.0030***
	(5.42)	(2.50)	(2.92)	(1.41)	(1.78)	(3.83)
R-square	0.78	0.61	0.62	0.22	0.33	0.58
Adj. R-square	0.76	0.58	0.59	0.17	0.27	0.54
Log of the Likelihood Fn.	1510.25	1179.24	647.34	971.23	894.13	1049.97
Durbin-H Stat.	0.11	-0.55	1.86	2.15	-0.51	-0.38

Notes: t-ratio is reported in parenthesis under coefficient; *** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and simple Naïve approach based on Tornqvist price index over commodities respectively.
Variance of Effective Exchange Rate in VP^{TornG}, VP^{TornM}, VP^{TornN}, and VP^{TornSN} models is lagged 6-month, while in VP^{TornSM} model is lagged 5-month;
Standard Deviation of Sunspot Index in VP^{TornG} is lagged 6-month while in VP^{TornN} is lagged 1-month;
Degree of International Trade Participation in VP^{TornG}, VP^{TornM}, VP^{TornN} , VP^{TornSG}, and VP^{TornSN} models is lagged 6-month while in VP^{TornSM} model is lagged 3-month.

Table 3.5: Elasticities at the Means for Major Explanatory Variables by Model

Dependent / Regressor	VP^{TornG}	VP^{TornM}	VP^{TornN}	VP^{TornSG}	VP^{TornSM}	VP^{TornSN}
Infrastructure Development Index	-0.053	-0.004	-0.001		-0.002	-0.003
Change Quota	0.016	0.007	0.104	0.219	0.242	0.141
Variance of Effective Exchange Rate	0.009	0.004	0.048		0.090	0.043
Standard Deviation of Sunspot Index	0.041		0.175			
Degree of International Trade Participation	0.003	0.003	0.008	0.0187	0.028	0.014

Notes: VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and simple Naïve approach based on Tornqvist price index over commodities respectively.

Table 3.6: Correlation Among Seasonality from Alternative Models						
	VP^{TornG}	VP^{TornM}	VP^{TornN}	VPT^{ornSG}	VP^{TornSM}	VP^{TornSN}
VP^{TornG}	1	0.76	0.72	-0.53	-0.46	0.77
VP^{TornM}		1	0.57	-0.38	-0.31	0.52
VP^{TornN}			1.00	-0.43	-0.43	0.94
VP^{TornSG}				1.00	0.85	-0.51
VP^{TornSM}					1	-0.54
VP^{TornSN}						1

Notes: VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and Naïve approach based on Tornqvist price index over commodities respectively.

Table 3.7: Multivariate Model Comparison for Explaining VP^{TornG}

Regressor \ Dependent	VPTornG (Model A)	Regressor \ Dependent	VPTornG (Model B)
Lag 1 of Dependent	0.66*** (18.1)	Lag 1 of Dependent	0.79*** (24.23)
Infrastructure Development Index	-0.00000029*** (-3.14)	Month_Jan	0.00019 (-1.04)
Change Quota	0.000000012** (2.09)	Month_Feb	-0.00032* (-1.75)
Variance of Effective Exchange Rate (Lag 6)	0.0000014*** (4.68)	Month_Mar	-0.00041** (-2.22)
Standard Deviation of Sunspot Index (Lag 6)	0.0000062* (1.88)	Month_Apr	0.000024 (0.13)
Degree of International Trade Participation (Lag 6)	0.0040* (1.90)	Month_May	-0.00034* (-1.84)
D9192	-0.00016 (-1.22)	Month_Jun	-0.00034* (-1.84)
D95	-0.00026 (-1.48)	Month_Jul	0.000042 (0.22)
D9899	0.00012 (0.92)	Month_Aug	-0.00065*** (-3.51)
		Month_Sep	-0.00043** (-2.33)
		Month_Oct	-0.00031* (-1.70)
		Month_Nov	-0.00045** (-2.48)
Constant	0.00083*** (4.96)		0.00082*** (5.37)
R-square	0.7556		0.7236
Adj. R-square	0.7463		0.7093
Log of the Likelihood Fn.	1497.14		1482.05
Durbin-H Stat.	0.23		-0.56
AIC	0.00000031		0.00000036

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
Model A excludes monthly dummies while keeps other explanatory variables;
Model B includes monthly dummies while exclude other explanatory variables;
VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH.

Table 3.8.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornSG} (all explanatory variables)

Regressor \ Dependent	VP^{TornG}	VP^{TornSG}
Lag 1 of Dependent	0.69***	-0.012
	(18.61)	(-0.19)
Lag 4 of Dependent	-0.020	0.30***
	(-0.58)	(4.73)
Infrastructure Development Index	-0.00000029***	0.00000036
	(-3.05)	(0.50)
Change Quota	0.000000011**	0.00000015***
	(1.98)	(2.90)
Variance of Effective Exchange Rate (Lag 6)	0.0000014***	-0.0000030
	(4.51)	(-1.13)
Standard Deviation of Sunspot Index (Lag 6)	0.0000051	0.000011
	(1.54)	(0.36)
Degree of International Trade Participation (Lag 6)	0.0039**	0.042***
	(1.90)	(2.232)
D9192	-0.00015	-0.0018
	(-1.14)	(-1.59)
D95	-0.00025	-0.0014
	(-1.50)	(-0.90)
D9899	0.00011	-0.000025
	(0.87)	(-0.023)
Month_Jan	-0.00016	-0.0014
	(-0.95)	(-0.8963)
Month_Feb	-0.00028	-0.0010102
	(-1.63)	(-0.66)
Month_Mar	-0.00036**	0.00028
	(-2.10)	(0.18)
Month_Apr	0.000062	-0.0018
	(0.37)	(-1.16)
Month_May	-0.00027	-0.0011
	(-1.60)	(-0.74)
Month_Jun	-0.00032*	0.0029*
	(-1.87)	(1.87)
Month_Jul	-0.000056	-0.0015
	(-0.32)	(-0.94)
Month_Aug	-0.00054***	-0.00059
	(-3.18)	(-0.39)
Month_Sep	-0.00040**	0.00030
	(-2.41)	(0.20)

Table 3.8.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornSG} (Continued)

Month_Oct	-0.00029*	-0.0019
	(-1.72)	(-1.23)
Month_Nov	-0.00041**	0.0030**
	(-2.49)	(2.00)
Constant	0.0011***	0.0011
	(5.17)	(0.76)
R-square	0.78	0.23
Adj. R-square	0.76	0.16
Log of the Likelihood Fn.	1510.44	972.00
Durbin-H Stat.	0.04	NA

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH; VP^{TornSG} denotes the aggregate price risk obtained from univariate GARCH model based on Tornqvist price index over commodities.

Table 3.8.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornSG} (excluding lagged dependent variables)

Regressor \ Dependent	VP^{TornG}	VP^{TornSG}
Infrastructure Development Index	-0.0000011***	0.00000035
	(-8.86)	(0.47)
Change Quota	0.000000024***	0.00000017***
	(2.67)	(3.16)
Variance of Effective Exchange Rate (Lag 6)	0.0000011**	-0.0000033
	(2.31)	(-1.16)
Standard Deviation of Sunspot Index (Lag 6)	0.0000074	-0.00000043
	(1.40)	(-0.014)
Degree of International Trade Participation (Lag 6)	0.0037	0.043**
	(1.12)	(2.24)
D9192	-0.00048**	-0.0023*
	(-2.39)	(-1.906)
D95	-0.00070***	-0.00054
	(-2.64)	(-0.35)
D9899	-0.000021	-0.000080
	(-0.11)	(-0.07)
Month_Jan	0.00012	-0.0010
	(0.44)	(-0.64)
Month_Feb	0.000036	-0.00010
	(0.13)	(-0.63)
Month_Mar	-0.000097	0.0014
	(-0.36)	(0.85)
Month_Apr	0.00020	-0.0015
	(0.74)	(-0.95)
Month_May	0.000078	-0.0012
	(0.29)	(-0.76)
Month_Jun	-0.000045	0.0028*
	(-0.17)	(1.74)
Month_Jul	0.00017	-0.00079
	(0.63)	(-0.49)
Month_Aug	0.000084	-0.00084
	(0.31)	(-0.53)
Month_Sep	-0.00013	0.00014
	(-0.50)	(0.09)
Month_Oct	-0.00016	-0.00088
	(-0.59)	(-0.56)
Month_Nov	-0.00038	0.0028*
	(-1.44)	(1.81)
Constant	0.0031***	0.0017
	(11.87)	(1.15)

Table 3.8.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornSG} (Continued)

R-square	0.44	0.15
Adj. R-square	0.39	0.08
Log of the Likelihood Fn.	1394.73	960.30
Durbin-Watson Stat.	0.53	2.10

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level; VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH; VP^{TornSG} denotes the aggregate price risk obtained from univariate GARCH model based on Tornqvist price index over commodities.

Table 3.8.c: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornSG} (excluding lagged dependent variables and monthly dummies)

Dependent / Regressor	VP^{TornG}	VP^{TornSG}
Infrastructure Development Index	-0.0000011*** (-8.81)	0.00000018 (0.24)
Change Quota	0.000000025*** (2.78)	0.00000016*** (2.93)
Variance of Effective Exchange Rate (Lag 6)	0.0000012*** (2.56)	-0.0000031 (-1.11)
Standard Deviation of Sunspot Index (Lag 6)	0.0000085* (1.664)	-0.000015 (-0.49)
Degree of International Trade Participation (Lag 6)	0.0036 (1.11)	0.044** (2.27)
D9192	-0.00048** (-2.42)	-0.0021* (-1.77)
D95	-0.00069** (-2.60)	-0.00064 (-0.40)
D9899	-0.0000068 (-0.035)	-0.00018 (-0.16)
Constant	0.0030*** (16.53)	0.0022** (2.00)
R-square	0.42	0.08
Adj. R-square	0.40	0.04
Log of the Likelihood Fn.	1390.23	949.59
Durbin-Watson Stat.	0.55	2.15

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH; VP^{TornSG} denotes the aggregate price risk obtained from univariate GARCH model based on Tornqvist price index over commodities.

Table 3.9.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornM} and VP^{TornSM} (all explanatory variables)

Regressor \ Dependent	VP^{TornM}	VP^{TornSM}
Lag 1 of Dependent	0.87*** (13.30)	-0.054 (-0.85)
Lag 2 of Dependent	-0.42*** (-4.93)	0.039 (0.62)
Lag 3 of Dependent	0.30*** (3.42)	0.027 (0.44)
Lag 4 of Dependent	0.020 (0.24)	0.30*** (4.80)
Lag 5 of Dependent	0.0054 (0.083)	0.093 (1.47)
Infrastructure Development Index	-0.0000000012*** (-3.79)	0.00000000016 (0.15)
Change Quota	0.000000015 (0.78)	0.00000024*** (3.51)
Variance of Effective Exchange Rate (Lag 6)	0.0000012 (1.09)	-0.00000050 (-0.13)
Degree of International Trade Participation (Lag 6)	0.023 (2.79)	0.086*** (3.21)
D9192	-0.00023 (-0.53)	-0.0023 (-1.47)
D95	-0.00036 (-0.57)	-0.0030 (-1.24)
D9899	0.00039 (0.86)	0.00027 (0.18)
Month_Jan	0.0015** (2.24)	-0.0029 (-1.31)
Month_Feb	0.00054 (0.81)	-0.003 (-1.52)
Month_Mar	0.00098 (1.49)	0.00081 (0.36)
Month_Apr	0.0015** (2.22)	-0.0034 (-1.54)
Month_May	0.00055 (0.81)	-0.0024 (-1.09)
Month_Jun	0.00081 (1.23)	0.00077 (0.35)
Month_Jul	0.00061 (0.91)	-0.0039* (-1.73)

Table 3.9.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornM} and VP^{TornSM} (Continued)

Month_Aug	-0.00052	-0.0032
	(-0.79)	(-1.47)
Month_Sep	-0.00036	-0.0012
	(-0.57)	(-0.55)
Month_Oct	0.00017	-0.0039*
	(0.27)	(-1.81)
Month_Nov	-0.00071	0.0030
	(-1.10)	(1.39)
Constant	0.0014	0.0028*
	(2.07)	(1.75)
R-square	0.61	0.28
Adj. R-square	0.57	0.20
Log of the Likelihood Fn.	1184.60	885.427
Durbin-H Stat.	NA	NA

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by M Het model; VP^{TornSM} denotes the aggregate price risk obtained from univariate M Het model based on Tornqvist price index over commodities.

Table 3.9.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornM} and VP^{TornSM} (excluding lagged dependent variables)

Regressor \ Dependent	VP^{TornM}	VP^{TornSM}
Infrastructure Development Index	-0.0000000016***	0.00000000028
	(-3.58)	(0.25)
Change Quota	0.000000045	0.00000030***
	(1.59)	(4.28)
Variance of Effective Exchange Rate (Lag 6)	0.000000087	-0.00000075
	(0.05)	(-0.19)
Degree of International Trade Participation (Lag 6)	0.0083	0.087***
	(0.76)	(3.19)
D9192	-0.00056	-0.0034**
	(-0.87)	(-2.18)
D95	-0.00033	0.00035
	(-0.36)	(0.16)
D9899	0.0015**	-0.00013
	(2.29)	(-0.09)
Month_Jan	0.0017*	-0.0021
	(1.81)	(-0.93)
Month_Feb	0.0020**	-0.0029
	(2.20)	(-1.29)
Month_Mar	0.0020**	0.0024
	(2.18)	(1.03)
Month_Apr	0.0029***	-0.0021
	(3.09)	(-0.91)
Month_May	0.0028***	-0.0019
	(3.03)	(-0.82)
Month_Jun	0.0027***	0.00073
	(2.91)	(0.32)
Month_Jul	0.0028***	-0.0023
	(2.96)	(-0.99)
Month_Aug	0.0017*	-0.0025
	(1.89)	(-1.10)
Month_Sep	0.00070	-0.00093
	(0.76)	(-0.41)
Month_Oct	0.00095	-0.0029
	(1.03)	(-1.27)
Month_Nov	0.00039	0.0031
	(0.43)	(1.39)
Constant	0.0063***	0.0032*
	(9.29)	(1.90)

Table 3.9.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornM} and VP^{TornSM} (Continued)

R-square	0.16	0.18
Adj. R-square	0.10	0.12
Log of the Likelihood Fn.	1090.33	869.86
Durbin-Watson Stat.	0.68	1.98

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level; VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by M Het model; VP^{TornSM} denotes the aggregate price risk obtained from univariate M Het model based on Tornqvist price index over commodities.

Table 3.9.c: Multivariate Model Comparison for Explaining Price Risk between VP^{TornM} and VP^{TornSM} (excluding lagged dependent variables and monthly dummies)

Regressor \ Dependent	VP^{TornM}	VP^{TornSM}
Infrastructure Development Index	-0.0000000014*** (-3.12)	-0.00000000034 (-0.30)
Change Quota	0.000000043 (1.48)	0.00000030*** (4.25)
Variance of Effective Exchange Rate (Lag 6)	0.00000072 (0.44)	-0.0000013 (-0.33)
Degree of International Trade Participation (Lag 6)	0.0085 (0.74)	0.087*** (3.14)
D9192	-0.00053 (-0.81)	-0.0034** (-2.15)
D95	-0.00028 (-0.30)	0.00032 (0.14)
D9899	0.0015** (2.25)	-0.00014 (-0.09)
Constant	0.0080*** (31.75)	0.0022*** (3.65)
R-square	0.07	0.11
Adj. R-square	0.04	0.09
Log of the Likelihood Fn.	1076.90	869.86
Durbin-Watson Stat.	0.65	2.02

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by M Het model; VP^{TornSM} denotes the aggregate price risk obtained from univariate M Het model based on Tornqvist price index over commodities.

Table 3.10.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornN} and VP^{TornSN} (all explanatory variables)

Regressor \ Dependent	VP^{TornN}	VP^{TornSN}
Lag 1 of Dependent	0.65***	0.61835***
	(13.93)	(11.96)
Lag 6 of Dependent	-0.075	0.035807
	(-1.53)	(0.62)
Infrastructure Development Index	-0.00000000050	-0.00000000037
	(-0.18)	(-0.69)
Change Quota	0.00000052***	0.00000011***
	(2.83)	(3.29)
Variance of Effective Exchange Rate (Lag 6)	0.000055***	0.0000075***
	(5.48)	(3.89)
Standard Deviation of Sunspot Index (Lag 6)	0.00015	0.0000046
	(1.56)	(0.24)
Degree of International Trade Participation (Lag 6)	0.148**	0.046***
	(2.09)	(3.30)
D9192	-0.0084**	-0.0012
	(-2.00)	(-1.56)
D95	0.0024	-0.00073
	(0.39)	(-0.58)
D9899	0.0013	0.000084
	(0.33)	(0.11)
Month_Jan	-0.0018	-0.0016
	(-0.32)	(-1.48)
Month_Feb	-0.015**	-0.0027
	(-2.59)	(-2.48)
Month_Mar	-0.020***	-0.0037***
	(-3.47)	(-3.42)
Month_Apr	-0.0041	-0.00082
	(-0.73)	(-0.76)
Month_May	-0.013**	-0.0026**
	(-2.22)	(-2.42)
Month_Jun	-0.014**	-0.0030
	(-2.42)	(-2.717)
Month_Jul	-0.011**	-0.0025**
	(-1.98)	(-2.25)
Month_Aug	-0.016***	-0.0029***
	(-2.79)	(-2.65)
Month_Sep	-0.016***	-0.0032***
	(-2.87)	(-2.95)

Table 3.10.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornN} and VP^{TornSN} (Continued)

Month_Oct	-0.011**	-0.0023**
	(-1.91)	(-2.18)
Month_Nov	-0.014**	-0.0029***
	(-2.48)	(-2.69)
Constant	0.014***	0.0028***
	(2.92)	(3.15)
R-square	0.62	0.58
Adj. R-square	0.59	0.54
Log of the Likelihood Fn.	647.34	1050.22
Durbin-H Stat.	1.86	-0.14

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by Naïve approach; VP^{TornSN} denotes the aggregate price risk obtained from Naïve approach based on Tornqvist price index over commodities.

Table 3.10.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornN} and VP^{TornSN} (excluding lagged dependent variables)

Regressor \ Dependent	VP^{TornN}	VP^{TornSN}
Infrastructure Development Index	0.00000000021	-0.00000000016
	(0.05)	(-0.23)
Change Quota	0.0000013***	0.00000022***
	(5.66)	(5.04)
Variance of Effective Exchange Rate (Lag 6)	0.000054***	0.0000072***
	(3.96)	(2.88)
Standard Deviation of Sunspot Index (Lag 6)	0.00023*	-0.000016
	(1.70)	(-0.67)
Degree of International Trade Participation (Lag 6)	0.24**	0.062***
	(2.61)	(3.61)
D9192	-0.020***	-0.0030***
	(-3.62)	(-2.92)
D95	0.0050	0.0025*
	(0.66)	(1.76)
D9899	0.00075	-0.00032
	(0.14)	(-0.32)
Month_Jan	0.0061	0.000028
	(0.79)	(0.020)
Month_Feb	-0.0027	-0.0011
	(-0.35)	(-0.75)
Month_Mar	-0.013*	-0.0028*
	(-1.69)	(-1.97)
Month_Apr	-0.0045	-0.00095
	(-0.58)	(-0.67)
Month_May	-0.0073	-0.0016
	(-0.95)	(-1.12)
Month_Jun	-0.011	-0.0023
	(-1.38)	(-1.61)
Month_Jul	-0.011	-0.0020
	(-1.34)	(-1.40)
Month_Aug	-0.0115	-0.0019
	(-1.48)	(-1.36)
Month_Sep	-0.015*	-0.0028**
	(-1.92)	(-1.98)
Month_Oct	-0.011	-0.0024*
	(-1.44)	(-1.67)
Month_Nov	-0.013*	-0.0027*
	(-1.73)	(-1.92)

Table 3.10.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornN} and VP^{TornSN} (Continued)

Constant	0.018 (2.798)	0.0043 (3.69)
R-square	0.30	0.27
Adj. R-square	0.24	0.21
Log of the Likelihood Fn.	570.65	982.81
Durbin-Watson Stat.	0.66	0.75

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level; VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by Naïve approach; VP^{TornSN} denotes the aggregate price risk obtained from Naïve approach based on Tornqvist price index over commodities.

Table 3.10.c: Multivariate Model Comparison for Explaining Price Risk between VP^{TornN} and VP^{TornSN} (excluding lagged dependent variables and monthly dummies)

Regressor \ Dependent	VP^{TornN}	VP^{TornSN}
Infrastructure Development Index	0.0000000011 (0.28)	-0.0000000000086 (-0.01)
Change Quota	0.0000013*** (5.66)	0.00000022*** (5.09)
Variance of Effective Exchange Rate (Lag 6)	0.000051*** (3.83)	0.0000068*** (2.79)
Standard Deviation of Sunspot Index (Lag 6)	0.00021 (1.60)	-0.000017 (-0.70)
Degree of International Trade Participation (Lag 6)	0.24** (2.60)	0.062*** (3.60)
D9192	-0.020*** (-3.56)	-0.0030*** (-2.90)
D95	0.004 (0.64)	0.0024* (1.75)
D9899	0.00086 (0.16)	-0.00030 (-0.30)
Constant	0.010 (2.84)	0.0026*** (3.95)
R-square	0.25	0.24
Adj. R-square	0.22	0.21
Log of the Likelihood Fn.	562.9	976.88
Durbin-Watson Stat.	0.69	0.78

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by Naïve approach; VP^{TornSN} denotes the aggregate price risk obtained from Naïve approach based on Tornqvist price index over commodities.

Table 3.11.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornM} (all explanatory variables)

Dependent / Regressor	VP^{TornG}	VP^{TornM}
Lag 1 of Dependent	0.69*** (15.19)	0.88*** (13.85)
Lag 2 of Dependent	-0.0074 (-0.14)	-0.44*** (-5.47)
Lag 3 of Dependent	0.0035 (0.08)	0.32*** (5.21)
Infrastructure Development Index	-0.00000027*** (-2.90)	-0.0000000012*** (-3.76)
Change Quota	0.000000011** (1.95)	0.000000015 (0.75)
Variance of Effective Exchange Rate (Lag 6)	0.0000013*** (4.44)	0.0000012 (1.09)
Standard Deviation of Sunspot Index (Lag 6)	0.0000049 (1.46)	-0.0000014 (-0.12)
Degree of International Trade Participation (Lag 6)	0.0041** (1.98)	0.022*** (2.77)
D9192	-0.00014 (-1.09)	-0.00022 (-0.46)
D95	-0.00026 (-1.52)	-0.00036 (-0.57)
D9899	0.00011 (0.88)	0.00040 (0.88)
Month_Jan	-0.00016 (-0.93)	0.0014** (2.20)
Month_Feb	-0.00027 (-1.59)	0.00049 (0.75)
Month_Mar	-0.00035** (-2.05)	0.00094 (1.45)
Month_Apr	0.000063 (0.37)	0.0014** (2.20)
Month_May	-0.00027 (-1.60)	0.00050 (0.75)
Month_Jun	-0.00031* (-1.84)	0.00079 (1.20)
Month_Jul	-0.000050 (-0.29)	0.00057 (0.86)
Month_Aug	-0.00054*** (-3.14)	-0.00053 (-0.80)

Table 3.11.a: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornM} (Continued)

Month_Sep	-0.00040**	-0.00037
	(-2.31)	(-0.58)
Month_Oct	-0.00028*	0.00015
	(-1.67)	(0.24)
Month_Nov	-0.00042**	-0.00072
	(-2.54)	(-1.13)
Constant	0.0010***	0.0016**
	(5.06)	(2.28)
R-square	0.78	0.61
Adj. R-square	0.76	0.57
Log of the Likelihood Fn.	1510.26	1179.25
Durbin-H Stat.	0.06	-0.65

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} and VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model and M Het model, respectively.

Table 3.11.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornM} (excluding lagged dependent variables)

Dependent / Regressor	VP^{TornG}	VP^{TornM}
Infrastructure Development Index	-0.0000011*** (-8.86)	-0.0000000016*** (-3.54)
Change Quota	0.000000024*** (2.67)	0.000000041 (1.44)
Variance of Effective Exchange Rate (Lag 6)	0.0000011** (2.31)	0.00000030 (0.18)
Standard Deviation of Sunspot Index (Lag 6)	0.0000074 (1.40)	-0.0000115 (-0.68)
Degree of International Trade Participation (Lag 6)	0.0037 (1.12)	0.0097 (0.86)
D9192	-0.00048** (-2.39)	-0.00038 (-0.55)
D95	-0.00070*** (-2.64)	-0.00037 (-0.41)
D9899	-0.000021 (-0.11)	0.0015** (2.27)
Month_Jan	0.00012 (0.44)	0.0017* (1.85)
Month_Feb	0.000036 (0.13)	0.0021* (2.22)
Month_Mar	-0.000097 (-0.36)	0.0020** (2.16)
Month_Apr	0.00020 (0.74)	0.0029*** (3.08)
Month_May	0.000078 (0.29)	0.0028*** (3.00)
Month_Jun	-0.000045 (-0.17)	0.0027*** (2.88)
Month_Jul	0.00017 (0.63)	0.0028*** (2.91)
Month_Aug	0.000084 (0.31)	0.0017* (1.79)
Month_Sep	-0.00013 (-0.50)	0.00067 (0.73)
Month_Oct	-0.00016 (-0.59)	0.00096 (1.04)
Month_Nov	-0.00038 (-1.44)	0.00036 (0.40)

Table 3.11.b: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornM} (Continued)

Constant	0.0031*** (11.87)	0.0065 (8.39)
R-square	0.44	0.17
Adj. R-square	0.39	0.10
Log of the Likelihood Fn.	1394.73	1085.70
Durbin-Watson Stat.	0.53	0.69

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} and VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model and M Het model, respectively.

Table 3.11.c: Multivariate Model Comparison for Explaining Price Risk between VP^{TornG} and VP^{TornM} (excluding lagged dependent variables and monthly dummies)

Dependent / Regressor	VP^{TornG}	VP^{TornM}
Infrastructure Development Index	-0.0000011*** (-8.81)	-0.0000000014 (-3.07)
Change Quota	0.000000025*** (2.78)	0.000000040 (1.35)
Variance of Effective Exchange Rate (Lag 6)	0.0000012** (2.56)	0.00000091 (0.55)
Standard Deviation of Sunspot Index (Lag 6)	0.0000085* (1.66)	-0.000011 (-0.67)
Degree of International Trade Participation (Lag 6)	0.0036 (1.11)	0.0097 (0.84)
D9192	-0.00048** (-2.42)	-0.00035 (-0.50)
D95	-0.00069** (-2.60)	-0.00033 (-0.35)
D9899	-0.0000068 (-0.035)	0.0015** (2.23)
Constant	0.0030*** (16.53)	0.0082*** (18.00)
R-square	0.42	0.07
Adj. R-square	0.40	0.04
Log of the Likelihood Fn.	1390.23	1072.30
Durbin-Watson Stat.	0.55	0.67

Notes: t-ratio is reported in parenthesis under coefficient;
*** denotes 1% significance level, ** 5% significance level, * 10% significant level;
VP^{TornG} and VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model and M Het model, respectively.

Table 4.1: Correlation Matrix Price Variances and Covariances

	$VarP^r$	$VarP^w$	$VarP^c$	$VarP^s$	$CVarP^{rw}$	$CVarP^{rc}$	$CVarP^{rs}$	$CVarP^{wc}$	$CVarP^{ws}$	$CVarP^{cs}$
$VarP^r$	1									
$VarP^w$	0.39	1								
$VarP^c$	0.14	0.09	1							
$VarP^s$	0.29	0.39	0.10	1						
$CVarP^{rw}$	0.68	0.49	0.06	0.37	1					
$CVarP^{rc}$	0.61	0.23	0.60	0.36	0.63	1				
$CVarP^{rs}$	0.64	0.25	0.09	0.77	0.70	0.63	1			
$CVarP^{wc}$	0.35	0.47	0.58	0.43	0.68	0.76	0.47	1		
$CVarP^{ws}$	0.37	0.48	0.15	0.75	0.73	0.45	0.76	0.72	1	
$CVarP^{cs}$	0.23	0.19	0.18	0.86	0.35	0.54	0.74	0.56	0.71	1

Notes: $VarP^r$, $VarP^w$, $VarP^c$, and $VarP^s$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively;

$CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively.

Table 4.2.a Unit Root Tests for Monthly Price Variances and Covariance

	Augmented Dickey-Fuller Test			
	Constant, No Trend		Constant,Trend	
Variable	T-Test	Ays. Critical Value (10%)	T-Test	Ays. Critical Value (10%)
$VarP^{r}$	-4.13	-2.57	-4.17	-3.13
$VarP^{w}$	-5.42	-2.57	-5.45	-3.13
$VarP^{c}$	-2.18	-2.57	-2.74	-3.13
$VarP^{s}$	-2.80	-2.57	-3.10	-3.13
$CVarP^{rw}$	-3.65	-2.57	-3.63	-3.13
$CVarP^{rc}$	-2.56	-2.57	-3.12	-3.13
$CVarP^{rs}$	-2.74	-2.57	-2.91	-3.13
$CVarP^{wc}$	-4.38	-2.57	-4.95	-3.13
$CVarP^{ws}$	-4.57	-2.57	-5.15	-3.13
$CVarP^{cs}$	-1.36	-2.57	-0.79	-3.13

Notes: $VarP^{r}$, $VarP^{w}$, $VarP^{c}$, and $VarP^{s}$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively;
$CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively.

Table 4.2.b Unit Root Tests for Monthly Price Variances and Covariance

	Phillips-Perron Test							
	Constant, No Trend				Constant,Trend			
Variable	T-Test	Ays. Critical Value (10%)	Z-Test	Ays. Critical Value (10%)	T-Test	Ays. Critical Value (10%)	Z-Test	Ays. Critical Value (10%)
$VarP^r$	-4.65	-2.57	-39.78	-11.20	-4.70	-3.13	-40.60	-18.20
$VarP^w$	-7.96	-2.57	-100.50	-11.20	-7.99	-3.13	-101.66	-18.20
$VarP^c$	-2.22	-2.57	-11.66	-11.20	-2.80	-3.13	-16.28	-18.20
$VarP^s$	-2.82	-2.57	-16.16	-11.20	-3.14	-3.13	-21.81	-18.20
$CVarP^{rw}$	-5.99	-2.57	-61.72	-11.20	-6.02	-3.13	-62.61	-18.20
$CVarP^{rc}$	-2.36	-2.57	-20.08	-11.20	-2.94	-3.13	-26.39	-18.20
$CVarP^{rs}$	-3.33	-2.57	-22.07	-11.20	-3.63	-3.13	-27.33	-18.20
$CVarP^{wc}$	-4.29	-2.57	-47.24	-11.20	-4.90	-3.13	-56.59	-18.20
$CVarP^{ws}$	-5.61	-2.57	-55.77	-11.20	-6.25	-3.13	-67.70	-18.20
$CVarP^{cs}$	-2.17	-2.57	-10.63	-11.20	-2.26	-3.13	-14.06	-18.20

Notes: $VarP^r$, $VarP^w$, $VarP^c$, and $VarP^s$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively;
$CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively.

Table 4.3.a: Correlogram of VarP^r

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|******|	.|******|	1	0.821	0.821	167.89	0.000
.|***** |	.|* |	2	0.712	0.116	294.60	0.000
.|***** |	.|. |	3	0.629	0.053	393.93	0.000
.|**** |	.|. |	4	0.553	0.006	471.10	0.000
.|*** |	*|. |	5	0.440	-0.142	520.19	0.000
.|*** |	.|. |	6	0.362	0.001	553.47	0.000
.|** |	.|. |	7	0.292	-0.020	575.18	0.000
.|** |	.|. |	8	0.237	0.014	589.63	0.000
.|* |	.|. |	9	0.196	0.031	599.47	0.000
.|* |	.|. |	10	0.143	-0.058	604.76	0.000
.|* |	.|. |	11	0.105	-0.001	607.62	0.000
.|* |	.|. |	12	0.075	-0.010	609.07	0.000

Notes: VarP^r denotes variance of rice price.

Table 4.3.b: Correlogram of VarP^{w}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|**** |	.|**** |	1	0.582	0.582	84.404	0.000
.|*** |	.|. |	2	0.365	0.039	117.69	0.000
.|** |	.|. |	3	0.253	0.039	133.71	0.000
.|* |	.|. |	4	0.187	0.026	142.53	0.000
.|* |	.|. |	5	0.103	-0.045	145.20	0.000
.|. |	.|. |	6	0.034	-0.039	145.49	0.000
.|. |	.|. |	7	-0.004	-0.018	145.49	0.000
.|. |	.|. |	8	0.003	0.029	145.49	0.000
.|. |	.|. |	9	-0.009	-0.014	145.52	0.000
.|. |	.|. |	10	-0.045	-0.046	146.04	0.000
.|. |	.|. |	11	-0.062	-0.022	147.04	0.000
*|. |	.|. |	12	-0.074	-0.030	148.47	0.000

Notes: VarP^{w} denotes variance of wheat price.

Table 4.3.c: Correlogram of VarP^c

Sample: 1987M07 2007M12

Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|* |	.|* |	1	0.140	0.140	4.9086	0.027
.|* |	.|* |	2	0.135	0.118	9.4767	0.009
.|* |	.|* |	3	0.133	0.104	13.949	0.003
.|* |	.|* |	4	0.133	0.094	18.423	0.001
.|* |	.|* |	5	0.134	0.087	22.981	0.000
.|* |	.|. |	6	0.121	0.066	26.710	0.000
.|* |	.|. |	7	0.114	0.054	30.000	0.000
.|* |	.|. |	8	0.112	0.050	33.224	0.000
.|* |	.|. |	9	0.109	0.045	36.289	0.000
.|* |	.|. |	10	0.111	0.046	39.477	0.000
.|* |	.|. |	11	0.114	0.048	42.870	0.000
.|* |	.|. |	12	0.084	0.014	44.723	0.000

Notes: VarP^c denotes variance of corn price.

Table 4.3.d: Correlogram of VarP^s

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|*******	.|*******	1	0.930	0.930	215.36	0.000
.|******|	.|. |	2	0.869	0.029	404.06	0.000
.|******|	.|. |	3	0.811	-0.004	569.18	0.000
.|******|	.|. |	4	0.763	0.044	715.92	0.000
.|***** |	.|. |	5	0.727	0.071	849.67	0.000
.|***** |	.|. |	6	0.695	0.025	972.49	0.000
.|***** |	.|. |	7	0.665	0.008	1085.4	0.000
.|***** |	.|. |	8	0.634	-0.006	1188.5	0.000
.|**** |	.|. |	9	0.606	0.016	1283.2	0.000
.|**** |	.|. |	10	0.585	0.044	1371.6	0.000
.|**** |	.|. |	11	0.564	0.006	1454.2	0.000
.|**** |	.|. |	12	0.543	-0.003	1531.1	0.000

Notes: VarP^s denotes variance of soybeans price.

Table 4.3.e: Correlogram of $CVarP^{rw}$

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.717	0.717	128.13	0.000
.|**** |	.|* |	2	0.593	0.161	216.03	0.000
.|**** |	.|* |	3	0.553	0.170	292.76	0.000
.|**** |	.|* |	4	0.542	0.147	366.79	0.000
.|*** |	*|. |	5	0.418	-0.141	411.06	0.000
.|** |	*|. |	6	0.307	-0.109	435.04	0.000
.|** |	*|. |	7	0.214	-0.117	446.76	0.000
.|* |	.|. |	8	0.174	-0.009	454.52	0.000
.|* |	.|. |	9	0.135	0.038	459.25	0.000
.|* |	.|. |	10	0.082	0.007	460.99	0.000
.|. |	.|. |	11	0.058	0.059	461.87	0.000
.|. |	.|. |	12	0.038	-0.003	462.24	0.000

Notes: $CVarP^{rw}$ denotes covariance of rice price and wheat price.

Table 4.3.f: Correlogram of $CVarP^{rc}$

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|******|	.|******|	1	0.799	0.799	158.87	0.000
.|***** |	.|** |	2	0.752	0.315	300.24	0.000
.|***** |	.|* |	3	0.710	0.144	426.77	0.000
.|***** |	.|* |	4	0.683	0.106	544.24	0.000
.|***** |	.|. |	5	0.624	-0.034	642.83	0.000
.|**** |	.|. |	6	0.579	-0.024	728.06	0.000
.|**** |	.|. |	7	0.533	-0.030	800.48	0.000
.|**** |	.|. |	8	0.489	-0.027	861.81	0.000
.|*** |	.|. |	9	0.464	0.038	917.22	0.000
.|*** |	.|. |	10	0.442	0.044	967.71	0.000
.|*** |	.|. |	11	0.406	-0.014	1010.4	0.000
.|*** |	.|. |	12	0.398	0.063	1051.8	0.000

Notes: $CVarP^{rc}$ denotes covariance of rice price and corn price.

Table 4.3.f: Correlogram of CVarP^{rc}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|******|	.|******|	1	0.799	0.799	158.87	0.000
.|***** |	.|** |	2	0.752	0.315	300.24	0.000
.|***** |	.|* |	3	0.710	0.144	426.77	0.000
.|***** |	.|* |	4	0.683	0.106	544.24	0.000
.|***** |	.|. |	5	0.624	-0.034	642.83	0.000
.|**** |	.|. |	6	0.579	-0.024	728.06	0.000
.|**** |	.|. |	7	0.533	-0.030	800.48	0.000
.|**** |	.|. |	8	0.489	-0.027	861.81	0.000
.|*** |	.|. |	9	0.464	0.038	917.22	0.000
.|*** |	.|. |	10	0.442	0.044	967.71	0.000
.|*** |	.|. |	11	0.406	-0.014	1010.4	0.000
.|*** |	.|. |	12	0.398	0.063	1051.8	0.000

Notes: CVarP^{rs} denotes covariance of rice price and soybeans price.

Table 4.3.g: Correlogram of CVarP^{rs}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|******|	.|******|	1	0.897	0.897	200.37	0.000
.|******|	.|* |	2	0.824	0.100	370.25	0.000
.|******|	.|. |	3	0.766	0.054	517.43	0.000
.|***** |	.|* |	4	0.725	0.084	650.00	0.000
.|***** |	**|. |	5	0.628	-0.285	749.70	0.000
.|**** |	.|. |	6	0.549	-0.020	826.24	0.000
.|*** |	.|. |	7	0.482	-0.002	885.52	0.000
.|*** |	.|. |	8	0.424	-0.021	931.58	0.000
.|*** |	.|* |	9	0.375	0.113	967.81	0.000
.|** |	.|. |	10	0.341	0.054	997.82	0.000
.|** |	.|. |	11	0.315	0.036	1023.5	0.000
.|** |	.|. |	12	0.285	-0.020	1044.7	0.000

Notes: CVarP^{wc} denotes covariance of wheat price and corn price.

Table 4.3.h: Correlogram of $CVarP^{wc}$

Date: 09/04/13 Time: 21:05
Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|***** |	.|***** |	1	0.698	0.698	121.48	0.000
.|**** |	.|* |	2	0.576	0.172	204.50	0.000
.|**** |	.|* |	3	0.508	0.111	269.40	0.000
.|*** |	.|. |	4	0.446	0.045	319.59	0.000
.|*** |	.|. |	5	0.381	0.001	356.32	0.000
.|** |	.|. |	6	0.321	-0.013	382.45	0.000
.|** |	.|. |	7	0.278	0.006	402.15	0.000
.|** |	.|. |	8	0.272	0.067	421.10	0.000
.|** |	.|. |	9	0.251	0.020	437.29	0.000
.|* |	.|. |	10	0.203	-0.042	447.95	0.000
.|* |	.|. |	11	0.184	0.011	456.70	0.000
.|* |	.|. |	12	0.156	-0.019	463.04	0.000

Notes: $CVarP^{ws}$ denotes covariance of wheat price and soybean price.

Table 4.3.i: Correlogram of $CVarP^{ws}$

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|******|	.|******|	1	0.763	0.763	145.07	0.000
.|**** |	.|. |	2	0.606	0.057	237.00	0.000
.|**** |	.|. |	3	0.498	0.044	299.37	0.000
.|*** |	.|. |	4	0.423	0.040	344.51	0.000
.|** |	.|. |	5	0.338	-0.039	373.52	0.000
.|** |	.|. |	6	0.289	0.038	394.68	0.000
.|** |	.|. |	7	0.266	0.053	412.68	0.000
.|** |	.|. |	8	0.260	0.058	430.05	0.000
.|** |	.|. |	9	0.247	0.018	445.76	0.000
.|** |	.|. |	10	0.223	-0.012	458.57	0.000
.|* |	.|. |	11	0.209	0.022	469.91	0.000
.|* |	.|. |	12	0.197	0.014	480.07	0.000

Notes: $CVarP^{cs}$ denotes covariance of corn and soybeans prices.

Table 4.3.j: Correlogram of CVarP^{cs}

Sample: 1987M07 2007M12
Included observations: 246

Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
.|*******	.|*******	1	0.950	0.950	224.50	0.000
.|*******	.|. |	2	0.904	0.027	428.92	0.000
.|******|	.|. |	3	0.860	-0.007	614.74	0.000
.|******|	.|. |	4	0.822	0.032	784.97	0.000
.|******|	.|* |	5	0.799	0.147	946.64	0.000
.|******|	.|. |	6	0.774	-0.026	1098.8	0.000
.|***** |	.|. |	7	0.750	0.007	1242.2	0.000
.|***** |	.|. |	8	0.732	0.071	1379.5	0.000
.|***** |	.|. |	9	0.714	0.025	1510.9	0.000
.|***** |	.|. |	10	0.702	0.036	1638.1	0.000
.|***** |	.|* |	11	0.701	0.141	1765.6	0.000
.|***** |	.|. |	12	0.702	0.065	1894.1	0.000

Notes: CVarP^{cs} denotes covariance of corn and soybeans prices.

Table 4.4: Correlation Matrix between the OLS Residuals from Different Equations

	$VarP^{r}$	$VarP^{w}$	$VarP^{c}$	$VarP^{s}$	$CVarP^{rw}$	$CVarP^{rc}$	$CVarP^{rs}$	$CVarP^{wc}$	$CVarP^{ws}$	$CVarP^{cs}$
$VarP^{r}$	1									
$VarP^{w}$	0.34	1								
$VarP^{c}$	0.06	0.28	1							
$VarP^{s}$	0.20	0.70	0.21	1						
$CVarP^{rw}$	-0.15	-0.06	0.00	-0.01	1					
$CVarP^{rc}$	-0.12	-0.08	0.06	-0.02	0.76	1				
$CVarP^{rs}$	-0.13	-0.09	0.05	-0.01	0.78	0.73	1			
$CVarP^{wc}$	-0.08	0.02	-0.02	0.02	0.82	0.57	0.46	1		
$CVarP^{ws}$	-0.05	-0.03	0.02	-0.02	0.80	0.44	0.69	0.78	1	
$CVarP^{cs}$	-0.13	-0.03	0.00	0.04	0.49	0.48	0.58	0.55	0.66	1

Notes: $VarP^{r}$, $VarP^{w}$, $VarP^{c}$, and $VarP^{s}$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively;

$CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively.

Breusch-Pagan test of Independence: chi2(45)= 1743.5, pr=0.0000;

Table 4.5.a: OLS and SUR Estimation Comparison

	$VarP^r$		$VarP^w$	
	OLS	SUR	OLS	SUR
Lag 1 of Dependent	0.64733*** (0.06701)	0.67132*** (0.06068)	0.55024*** (0.05504)	0.54662*** (0.03896)
Lag 2 of Dependent	0.14091** (0.0684)	0.10219** (0.06203)		
Infrastructure Development Index	-0.00000062075* (0.0000003702)	-0.0000006589* (0.0000003385)		
Change Quota	0.000000016801* (0.000000009339)	0.000000018334* (0.000000008758)	0.000000011301 (0.000000007882)	0.000000015991*** (0.000000005692)
Variance of Effective Exchange Rate	0.000001235*** (0.0000004222)	0.0000012333*** (0.0000003943)	0.00000070388 (0.0000004611)	0.000000709** (0.0000003171)
Standard Deviation of Sunspot Index	0.0000048277 (0.000004706)	0.0000056752 (0.000004262)		
Degree of International Trade Participation	0.0096843*** (0.003061)	0.0092853*** (0.002973)	0.0088503*** (0.003278)	0.010386*** (0.003083)
Change Income	0.00000050476** (0.0000002515)	0.00000053561** (0.0000002302)		
D9192	-0.00025917 (0.0001819)	-0.00027795 (0.0001761)	-0.00030402 (0.0001839)	-0.000271 (0.0001751)
D95	-0.0002481(0.0002443)	-0.00019317 (0.0002325)	-0.000092074 (0.0002603)	-0.000040618 (0.0001842)
D9899	0.00016649 (0.0001772)	0.00017131 (0.000164)		
Month_Jan	-0.00022561 (0.000239)	-0.00024089 (0.000236)	-0.00082887*** (0.0002679)	-0.00082558*** (0.0002661)
Month_Feb	-0.00025771 (0.0002375)	-0.00026276 (0.0002347)	-0.00071957*** (0.0002652)	-0.0007177*** (0.0002647)
Month_Mar	-0.00033129 (0.000237)	-0.00033461 (0.0002343)	-0.00081211*** (0.0002648)	-0.00081063*** (0.0002645)
Month_Apr	0.00025408 (0.0002372)	0.00025018 (0.0002345)	-0.0005484** (0.0002644)	-0.00054747** (0.0002643)
Month_May	-0.00023531 (0.0002403)	-0.00025615 (0.0002371)	-0.00085373*** (0.0002649)	-0.00085217*** (0.0002646)
Month_Jun	-0.00029713 (0.0002372)	-0.00029409 (0.0002345)	-0.00080498*** (0.0002647)	-0.00080447*** (0.0002644)
Month_Jul	0.000075217 (0.0002411)	0.000072321 (0.000238)	-0.00057933** (0.0002688)	-0.00057939** (0.0002664)
Month_Aug	-0.00027543 (0.0002394)	-0.00029079 (0.0002363)	-0.00071907*** (0.0002649)	-0.00071769*** (0.0002646)
Month_Sep	-0.00028412 (0.0002344)	-0.0002786 (0.0002317)	-0.00073346*** (0.0002617)	-0.00073167*** (0.0002614)
Month_Oct	-0.000043114 (0.0002341)	-0.000047323 (0.0002314)	-0.0007681*** (0.0002614)	-0.00076629*** (0.0002612)
Month_Nov	-0.00016054 (0.0002323)	-0.0001674 (0.0002295)	-0.00084944*** (0.0002584)	-0.00084695*** (0.0002583)
Constant	0.00021318 (0.0002402)	0.00021096 (0.0002281)	0.0011281 (0.000195)	0.0011045 (0.0001912)
R-square	0.7391	0.7383	0.4211	0.4194
Adj. R-square	0.7145		0.3775	
Durbin-H Stat.	NA		0.03	

Notes: $VarP^r$ and $VarP^w$ denotes variance of rice price and variance of wheat price, respectively;
Standard error are reported in parenthesis;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level;
Variance of Effective Exchange Rate is in the form of lagged 6-month;
Standard Deviation of Sunspot Index is in the form of lagged 6-month ;
Degree of International Trade Participation is lagged 6-month in both $VarP^r$ and $VarP^w$ models.

Table 4.5.b OLS and SUR Estimation Comparison

	$VarP^c$		$VarP^s$	
	OLS	SUR	OLS	SUR
Lag 1 of Dependent	0.977*** (0.01955)	0.96724*** (0.01886)	0.90924*** (0.02787)	0.91249*** (0.02143)
Infrastructure Development Index	-0.00000000020529*** (0.00000000002698)	-0.00000000020596*** (0.000000000026)	-0.0000000014572*** (0.0000000003396)	-0.000000001447*** (0.0000000002416)
Change Quota	0.0000000052089*** (0.000000001611)	0.0000000050696*** (0.000000001578)		
Degree of International Trade Participation			0.014879* (0.008151)	0.017073** (0.007975)
D9192			-0.00064442 (0.0005016)	-0.00055695 (0.0004801)
D95	-0.00012394** (0.00005544)	-0.00010487* (0.00005407)		
D9899			0.00070677 (0.0005473)	0.00073019* (0.0003944)
Month_Jan	0.000016084 (0.00005478)	0.000017069 (0.00005502)	-0.0013057* (0.0006894)	-0.0013097* (0.0006906)
Month_Feb	-0.00014091** (0.00005491)	-0.0001388** (0.00005514)	-0.0014525** (0.0006892)	-0.0014559** (0.0006904)
Month_Mar	-0.00012392** (0.00005485)	-0.00012224** (0.00005508)	-0.0011563* (0.0006889)	-0.0011586* (0.0006903)
Month_Apr	-0.00010423** (0.00005482)	-0.0001028* (0.00005506)	-0.0011594* (0.0006889)	-0.0011617* (0.0006903)
Month_May	-0.00015491*** (0.00005481)	-0.00015354*** (0.00005505)	-0.00092068 (0.0006889)	-0.00092296 (0.0006903)
Month_Jun	-0.000095358* (0.00005477)	-0.00009454* (0.00005501)	-0.0018777*** (0.0006891)	-0.001881*** (0.0006904)
Month_Jul	-0.00010876** (0.00005477)	-0.00010789* (0.00005501)	-0.0014738 ** (0.0006886)	-0.0014747** (0.0006901)
Month_Aug	-0.00011061** (0.00005477)	-0.00010984** (0.00005501)	-0.0013269* (0.0006886)	-0.001327* (0.0006901)
Month_Sep	-0.00012028** (0.0000541)	-0.00011966** (0.00005434)	-0.0014305** (0.0006804)	-0.0014293** (0.0006819)
Month_Oct	-0.00012498** (0.0000541)	-0.00012456** (0.00005433)	-0.0015301** (0.0006804)	-0.0015283** (0.0006819)
Month_Nov	-0.00011482** (0.00005409)	-0.00011481** (0.00005428)	-0.00047453 (0.0006806)	-0.00047505 (0.0006782)
Constant	0.00010982*** (0.00004391)	0.00011901*** (0.00004374)	0.0018609*** (0.0005277)	0.0018242*** (0.0005133)
R-square	0.9239	0.9238	0.8870	0.8870
Adj. R-square	0.9188		0.8791	
Durbin-H Stat.	0.07		0.34	

Notes: $VarP^c$ and $VarP^s$ denotes variance of corn price and variance of soybeans price, respectively;
Standard error are reported in parenthesis;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level;
Degree of International Trade Participation is lagged 6-month in VarPs model.

Table4.5.c: OLS and SUR Estimation Comparison				
	$CVarP^{rw}$		$CVarP^{rc}$	
	OLS	SUR	OLS	SUR
Lag 1 of Dependent	0.59779*** (0.06457)	0.70845*** (0.02652)	0.80982*** (0.06575)	0.88747*** (0.0358)
Lag 2 of Dependent	0.1533** (0.06411)	0.074979*** (0.02085)	0.11964* (0.06513)	0.042023 (0.03445)
Infrastructure Development Index	-0.00000000002039 (0.0000000000458)	-0.0000000000412 (0.00000000002689)	-0.00000000013814*** (0.000000000008741)	-0.00000000013965*** (0.000000000007755)
Change Quota	0.0000000085918*** (0.000000002773)	0.0000000050169*** (0.0000000009075)	0.0000000012645** (0.0000000005071)	0.00000000059541** (0.0000000002701)
Standard Deviation of Sunspot Index	0.0000027417 (0.000001782)	0.0000018725*** (0.0000005306)		
Degree of International Trade Participation	0.0030467*** (0.001108)	0.0029226*** (0.0009403)	0.00039812* (0.0002151)	0.000381** (0.0001844)
Change Income	0.000000055228** (0.00000002872)	0.000000025579* (0.00000001457)	0.0000000055893 (0.000000004846)	0.0000000027171 (0.000000003776)
Month_Jan	0.00026729*** (0.00009186)	0.00027907*** (0.00009149)	0.000046425** (0.00001775)	0.00004791*** (0.00001772)
Month_Feb	0.00004356 (0.00009272)	0.000023704 (0.00009161)	0.000022222 (0.00001787)	0.000019845 (0.00001776)
Month_Mar	0.000019205 (0.00009208)	0.000028721 (0.0000915)	-0.000000017012 (0.00001773)	0.00000015198 (0.00001772)
Month_Apr	-0.0000072139 (0.00009179)	-0.00000089484 (0.00009147)	-0.0000066953 (0.00001776)	-0.0000050788 (0.00001773)
Month_May	0.00018526** (0.00009185)	0.00019623** (0.00009148)	0.000029605* (0.00001777)	0.00003149* (0.00001773)
Month_Jun	-0.0000047286 (0.00009216)	-0.000013429 (0.00009152)	-0.0000007946 (0.00001776)	-0.0000018525 (0.00001773)
Month_Jul	0.0000046548 (0.00009199)	0.000016568 (0.00009149)	0.0000042174 (0.00001776)	0.0000059804 (0.00001773)
Month_Aug	0.00018451** (0.00009182)	0.00019441** (0.00009148)	0.000040644** (0.00001773)	0.000041594** (0.00001772)
Month_Sep	0.000019855 (0.00009124)	0.000013151 (0.00009042)	-0.00000213 (0.00001758)	-0.0000039022 (0.00001752)
Month_Oct	0.000018891 (0.0000909)	0.000029439 (0.00009039)	0.00000026544 (0.00001756)	0.0000020858 (0.00001751)
Month_Nov	0.000070022 (0.00009065)	0.000078289 (0.00008971)	0.000010636 (0.00001752)	0.000011142 (0.00001746)
Constant	-0.000055344 (0.0000931)	-0.000018895 (0.00006829)	-0.0000016982 (0.00001476)	0.0000030894 (0.00001347)
R-square	0.6027	0.5945	0.8807	
Adj. R-square	0.5709		0.8717	
Durbin-H Stat.	NA		NA	

Notes: $CVarP^{rw}$ and $CVarP^{rc}$ denotes covariance of rice price and wheat price and covariance of rice price and corn price, respectively;
Standard error are reported in parenthesis;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level;
Standard Deviation of Sunspot Index is lagged 2-month in CVarPrw model;
Degree of International Trade Participation is lagged 6-month in both CVarPrw and CVarPrc model.

Table 4.5.d OLS and SUR Estimation Comparison

	$CVarP^{rs}$		$CVarP^{wc}$	
	OLS	SUR	OLS	SUR
Lag 1 of Dependent	0.81722*** (0.06482)	0.88872*** (0.03255)	0.78678*** (0.0404)	0.83454*** (0.02122)
Lag 2 of Dependent	0.085816 (0.06511)	0.017303 (0.03003)		
Infrastructure Development Index	-0.00000000012478** (0.00000000005582)	-0.00000000012467*** (0.00000000003972)	-0.0000000011738*** (0.00000000001147)	-0.00000000011629*** (0.00000000000714)
Degree of International Trade Participation	0.0046426*** (0.001351)	0.004688*** (0.00108)	0.00030719 (0.0002763)	0.00026302 (0.0002301)
Change Income	0.00000003947 (0.00000003367)	0.000000037735 (0.00000002489)		
D9192	-0.000082785 (0.00008406)	0.0000041043 (0.00004509)	-0.000033784** (0.00001694)	-0.0000088049 (0.000008888)
D9899	0.000063812 (0.00008453)	0.000077907** (0.00003566)		
Month_Jan	0.00016713 (0.0001131)	0.00016604 (0.0001128)	0.000077031*** (0.0000233)	0.000077865*** (0.00002339)
Month_Feb	-0.000027066 (0.0001137)	-0.000040412 (0.000113)	0.000011404 (0.00002336)	0.0000092157 (0.00002341)
Month_Mar	-0.000059563 (0.0001132)	-0.000057271 (0.0001128)	0.000010213 (0.00002332)	0.0000087806 (0.0000234)
Month_Apr	-0.000070482 (0.0001132)	-0.000067442 (0.0001128)	0.000010379 (0.0000233)	0.0000095985 (0.00002339)
Month_May	0.00013733 (0.0001132)	0.00014087 (0.0001128)	0.000037301 (0.00002329)	0.000037026 (0.00002339)
Month_Jun	-0.000022268 (0.0001136)	-0.000033854 (0.0001129)	-0.0000014524 (0.00002331)	-0.0000026114 (0.0000234)
Month_Jul	-0.000094995 (0.0001132)	-0.000093291 (0.0001128)	0.000014373 (0.00002329)	0.000014364 (0.00002339)
Month_Aug	0.000095694 (0.0001132)	0.00010126 (0.0001128)	0.000044748* (0.00002329)	0.000044888* (0.00002339)
Month_Sep	-0.000068513 (0.0001119)	-0.00007594 (0.0001115)	0.000010769 (0.00002303)	0.0000097576 (0.00002312)
Month_Oct	-0.000071711 (0.0001118)	-0.000066616 (0.0001114)	0.000011741 (0.00002301)	0.000011282 (0.00002311)
Month_Nov	-0.000029016 (0.0001117)	-0.000024851 (0.0001108)	0.000013808 (0.00002301)	0.000014198 (0.00002295)
Constant	0.000090855 (0.00009157)	0.000079276 (0.00008377)	0.000032154 (0.00001902)	0.00001928 (0.00001726)
R-square	0.8364	0.8345	0.7225	0.7193
Adj. R-square	0.8233		0.7043	
Durbin-H Stat.	NA		-0.81	

Notes: $CVarP^{rs}$ and $CVarP^{wc}$ denotes covariance of rice price and soybeans price and covariance of wheat price and corn price, respectively;
Standard error are reported in parenthesis;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level;
Degree of International Trade Participation is lagged 6-month in both $CVarP^{rs}$ and $CVarP^{wc}$ models.

Table 4.5.e: OLS and SUR Estimation Comparison

	$CVarP^{ws}$		$CVarP^{cs}$	
	OLS	SUR	OLS	SUR
Lag 1 of Dependent	0.68445*** (0.04709)	0.79203*** (0.02287)	0.079692 (0.06663)	0.063119 (0.04161)
Infrastructure Development Index	-0.00000029558** (0.0000001467)	0.000000057485 (0.00000005542)	0.00000041095*** (0.00000007168)	0.00000040019*** (0.00000005128)
Degree of International Trade Participation	0.0041004** (0.001627)	0.0033696*** (0.001174)		
Standard Deviation of Sunspot Index	0.0000033731 (0.000002522)	0.0000019993** (0.0000009264)		
Change Income	0.0000002813** (0.0000001081)	0.000000011391 (0.00000004261)		
D9192	-0.00019652** (0.00009866)	-0.000051409 (0.00003838)		
D95	-0.00010621 (0.0001354)	-0.00004108 (0.00004817)		
D9899	0.00022026** (0.0001032)	0.00011334** (0.00003987)		
Month_Jan	0.00032913** (0.0001322)	0.00034032* (0.0001314)	-0.0000098378 (0.00004146)	-0.0000079375 (0.00004144)
Month_Feb	-0.000017735 (0.0001327)	-0.000041987 (0.0001316)	0.0000036419 (0.00004112)	0.000005066 (0.00004124)
Month_Mar	0.00001398 (0.0001323)	0.0000042114 (0.0001315)	-0.00006501 (0.00004094)	-0.000063975 (0.00004117)
Month_Apr	0.0000012099 (0.0001322)	-0.0000036905 (0.0001314)	-0.000035446 (0.00004073)	-0.00003558 (0.00004108)
Month_May	0.00010688 (0.0001321)	0.00010826 (0.0001314)	-0.000030878 (0.00004074)	-0.000030615 (0.00004109)
Month_Jun	-0.0000252 (0.0001323)	-0.000028493 (0.0001315)	-0.00004655 (0.00004075)	-0.000046179 (0.00004109)
Month_Jul	-0.000033897 (0.0001321)	-0.000033304 (0.0001314)	-0.000064747 (0.00004073)	-0.000064628 (0.00004108)
Month_Aug	0.000096519 (0.0001322)	0.00010767 (0.0001314)	-0.000042727 (0.00004073)	-0.00004293 (0.00004109)
Month_Sep	0.000022001 (0.000131)	0.0000265 (0.0001299)	-0.00003248 (0.00004024)	-0.000032333 (0.00004059)
Month_Oct	0.0000055016 (0.0001307)	0.0000080365 (0.0001299)	-0.000049911 (0.00004026)	-0.000049576 (0.0000406)
Month_Nov	0.00001421 (0.0001291)	0.0000077974 (0.0001284)	-0.000057361 (0.00004017)	-0.000058123 (0.00004033)
Constant	0.000055978 (0.0001281)	0.000047304 (0.00009942)	0.000032876 (0.00002883)	0.000032533 (0.00002906)
R-square	0.6359	0.6184	0.1785	0.1782
Adj. R-square	0.6050		0.1321	
Durbin-H Stat.	-0.18		NA	

Notes: $CVarP^{ws}$ and $CVarP^{cs}$ denotes covariance of wheat price and soybeans price and covariance of corn price and soybeans price, respectively;
Standard error are reported in parenthesis;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level;
Standard Deviation of Sunspot Index is in the form of lagged 2-month;
Degree of International Trade Participation is lagged 6-month in both $CVarP^{ws}$ model

Table 4.6: Correlation Matrix between Monthly Seasonality from Different Models

	$VarP^r$	$VarP^w$	$VarP^c$	$VarP^s$	$CVarP^{rw}$	$CVarP^{rc}$	$CVarP^{rs}$	$CVarP^{wc}$	$CVarP^{ws}$	$CVarP^{cs}$
$VarP^r$	1.00									
$VarP^w$	0.79	1.00								
$VarP^c$	0.00	-0.09	1.00							
$VarP^s$	-0.01	-0.27	-0.15	1.00						
$CVarP^{rw}$	-0.43	-0.43	0.50	0.31	1.00					
$CVarP^{rc}$	-0.46	-0.34	0.42	0.19	0.94	1.00				
$CVarP^{rs}$	-0.50	-0.49	0.43	0.22	0.96	0.91	1.00			
$CVarP^{wc}$	-0.28	-0.27	0.67	0.19	0.96	0.90	0.89	1.00		
$CVarP^{ws}$	-0.32	-0.38	0.76	0.14	0.91	0.79	0.85	0.96	1.00	
$CVarP^{cs}$	-0.21	-0.07	0.27	-0.16	0.35	0.48	0.42	0.40	0.41	1.00

Notes: $VarP^r$, $VarP^w$, $VarP^c$, and $VarP^s$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively;
$CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively.

Table 4.7: Elasticities at the Means for Major Independent Variables

	$VarP^r$	$VarP^w$	$VarP^c$	$VarP^s$	$CVarP^{rw}$	$CVarP^{rc}$	$CVarP^{rs}$	$CVarP^{wc}$	$CVarP^{ws}$	$CVarP^{cs}$
Infrastructure Development Index	-0.20**		-0.0051***	-0.0052***	-0.002	-0.013***	-0.0024***	-0.013***	-0.034	0.14***
Change Quota	0.037*	0.060***	0.019***		0.031***	0.0079**				
Variance of Effective Exchange Rate	0.012***	0.012**								
Standard Deviation of Sunspot Index	0.072				0.065***				0.052**	
International Trade Participation	0.0046***	0.010***		0.0023**	0.0046***	0.0013**	0.0037***	0.0011	0.0039***	
Change Income per Capita	0.28**				0.036*	0.0083	0.026		0.013	

Notes: $VarP^r$, $VarP^w$, $VarP^c$, and $VarP^s$ denotes variance of rice price, variance of wheat price, variance of corn price, and variance of soybeans price, respectively; $CVarP^{rw,}$ $CVarP^{rc}$, $CVarP^{rs}$, $CVarP^{wc}$, $CVarP^{ws}$, and $CVarP^{cs}$ denotes covariance of rice price and wheat price, covariance of rice price and corn price, covariance of rice price and soybeans price, covariance of wheat price and corn price, covariance of wheat price and soybean price, and covariance of corn and soybeans prices respectively;
*** denotes significant at 1% conventional level, ** at 5% level, and * at 10% level

Table 4.8: Test the Equality of Coefficients across SUR Equations

Variable	F-statistics	P-value
Infrastructure Development Index	16.93	0.00000
Change Quota	12.05	0.00000
Variance of Effective Exchange Rate	1.20	0.23100
Standard Deviation of Sunspot Index	0.38	0.68251
Degree of International Trade Participation	5.52	0.00000
Change Income	2.49	0.04132
D9192	1.02	0.40168
D95	0.48	0.69742
D9899	1.27	0.28265

Figure 2.1: Monthly Market Price of Major Grains in China, 1987 -2007

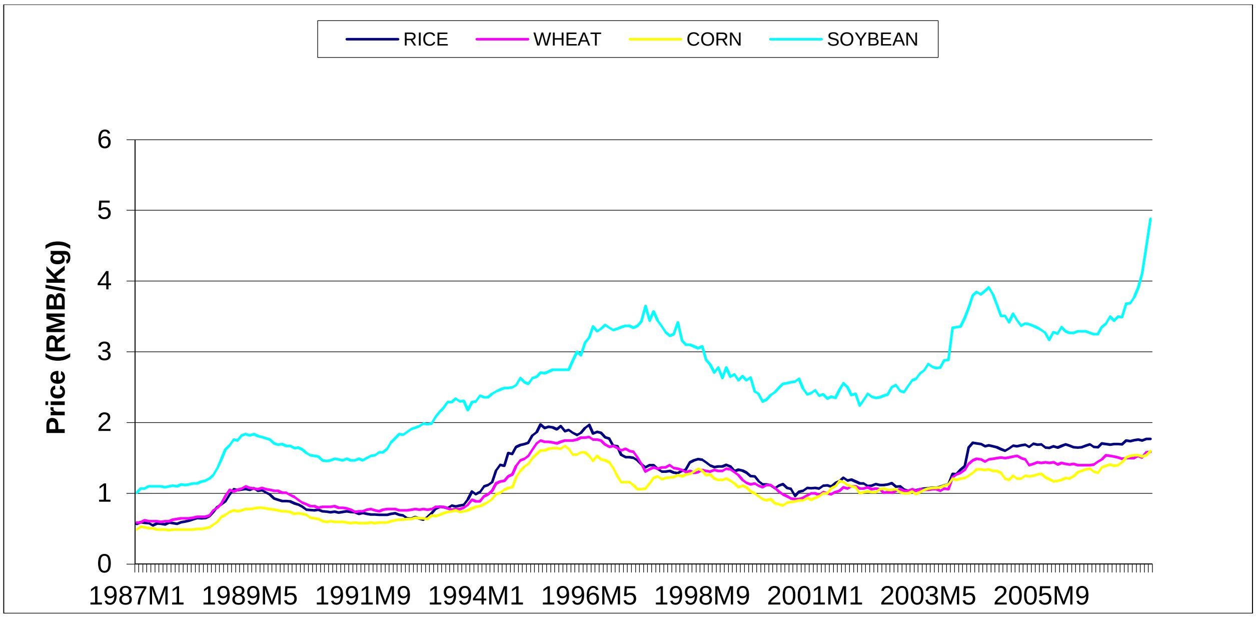
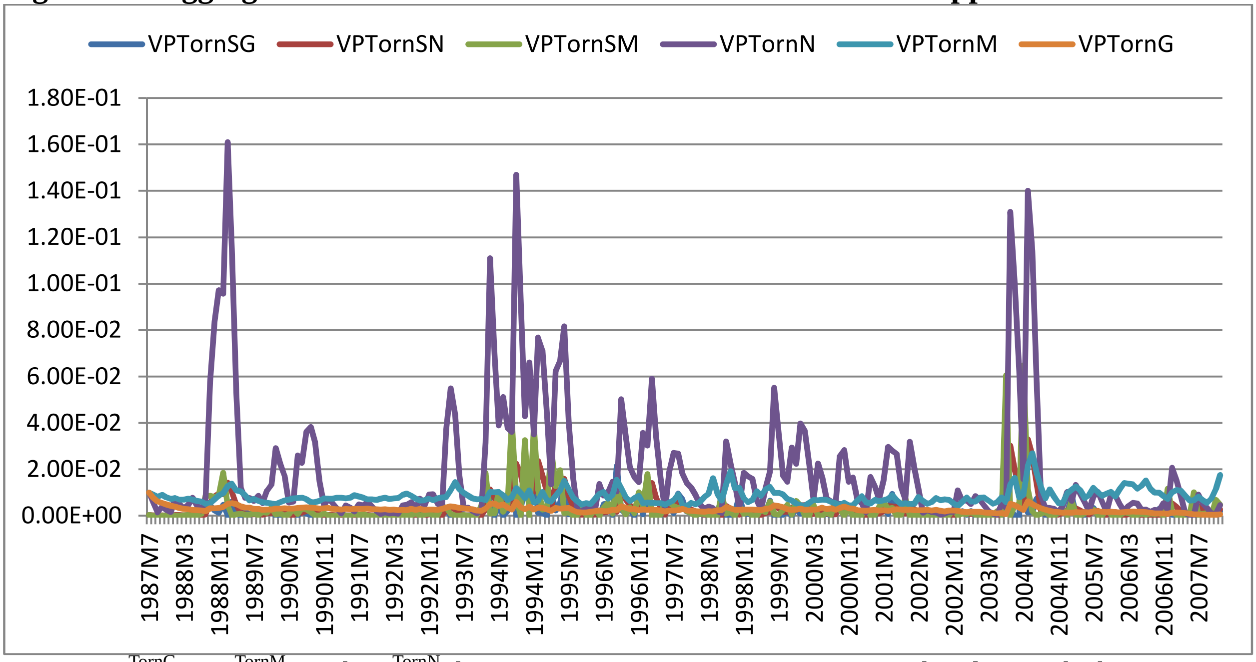
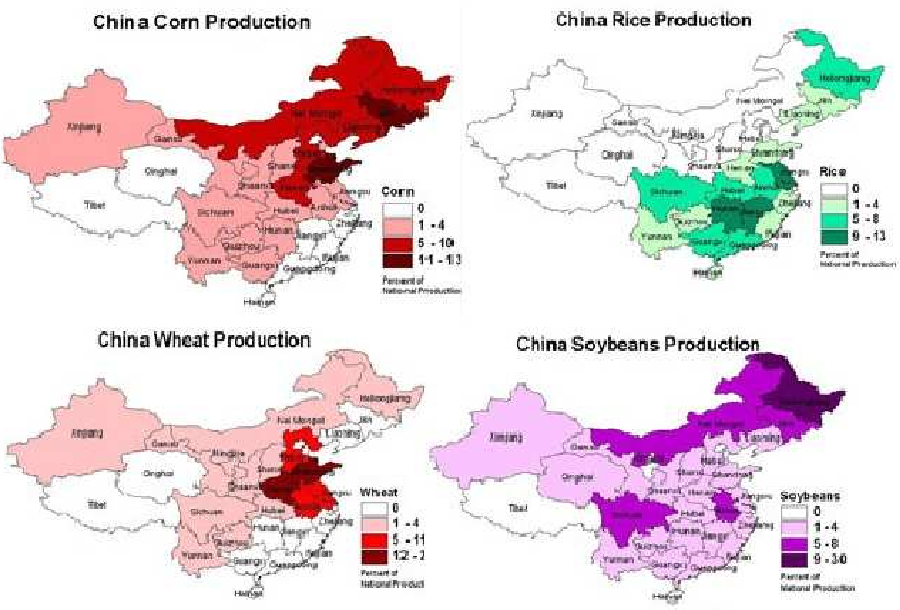


Figure 2.2: Aggregated Price Risk Indexes Obtained from Different Approaches



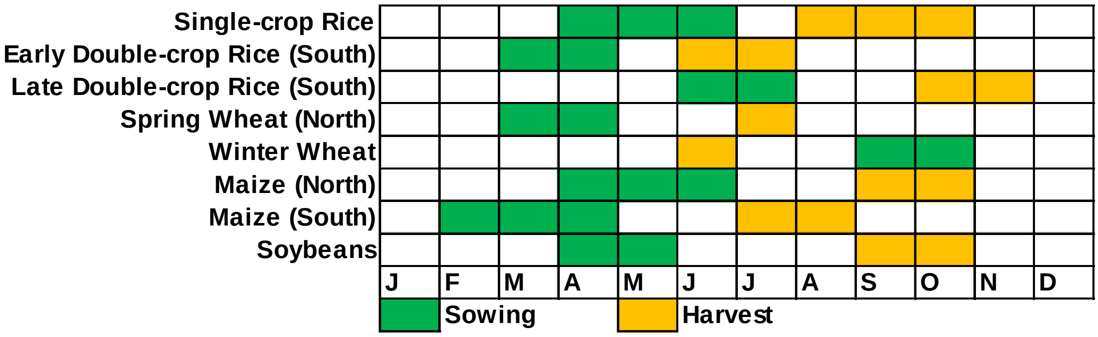
Notes: VP^{TornG} , VP^{TornM} , and VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model, M Het model, Naïve approach respectively; VP^{TornSG} , VP^{TornSM}, and VP^{TornSN} denotes the aggregate price risk obtained from univariate GARCH model, univariate M Het model, and Naïve approach based on Tornqvist price index over commodities respectively.

Figure 3.1: China's Crop Regions and Production Distribution Map



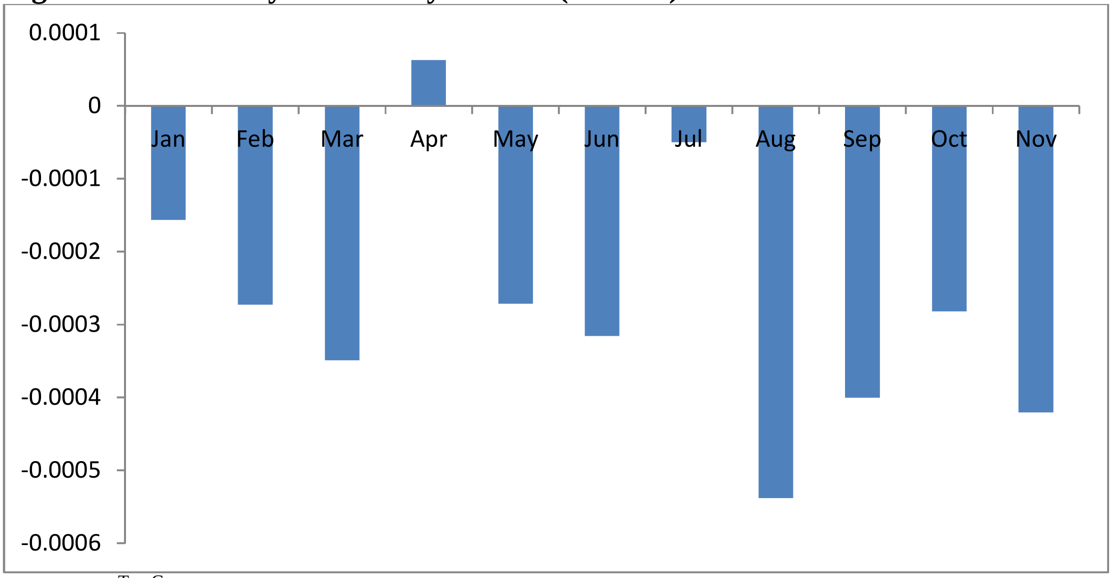
Notes: Maps are adapted from
http://www.air-worldwide.com/Publications/AIR-Currents/Agricultural-Risk-and-the-Crop-Insurance-Market-in-China/

Figure 3.2: China's Crop Planting and Harvesting Calendar



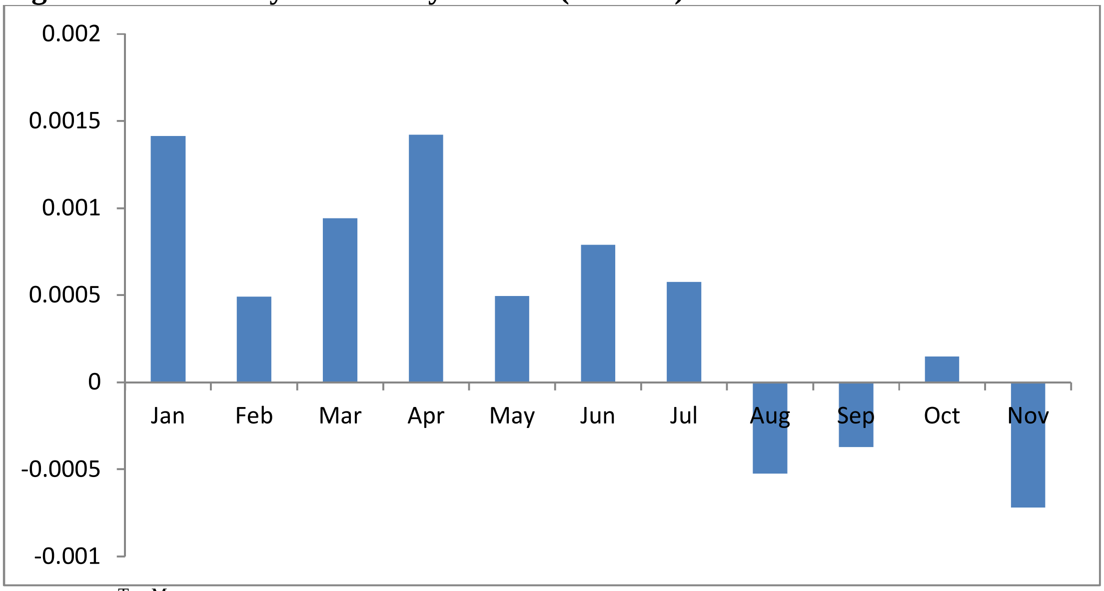
Notes: Data source is Food and Agriculture Organization of the United Nations

Figure 3.3.a Monthly Seasonality Pattern (VP^{TornG})



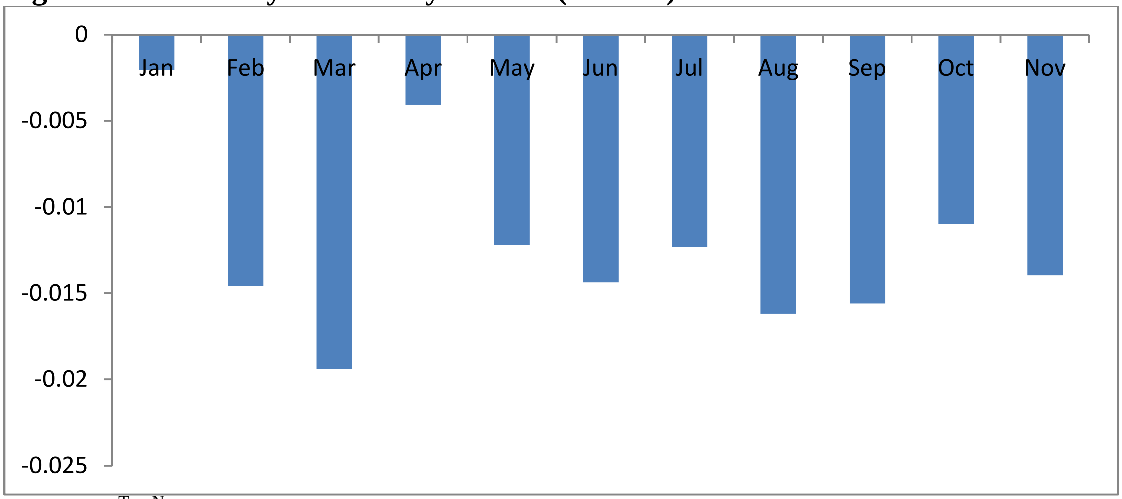
Notes: VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by GARCH model.

Figure 3.3.b Monthly Seasonality Pattern (VP^{TornM})



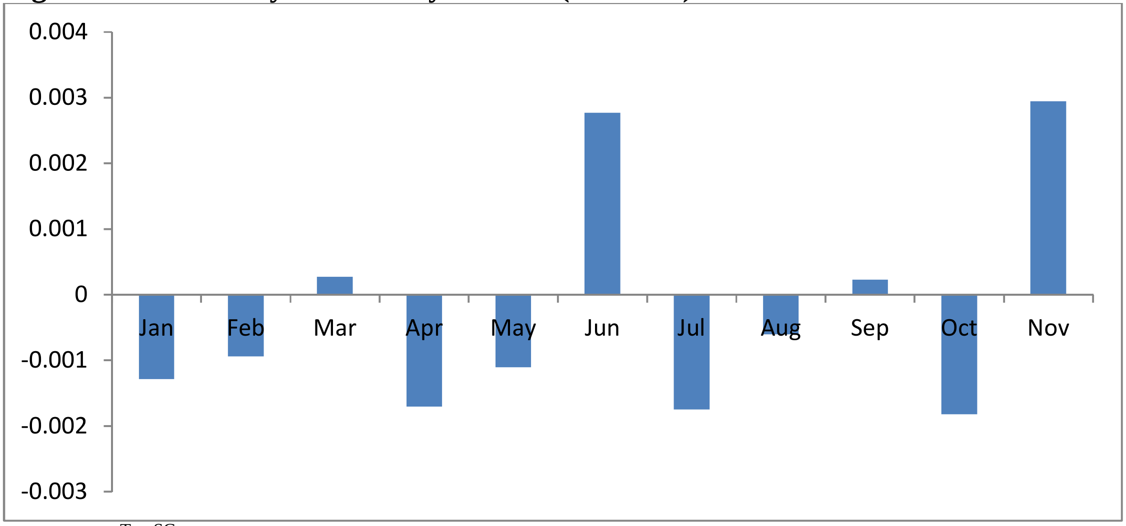
Notes: VP^{TornM} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by M Het model.

Figure 3.3.c Monthly Seasonality Pattern (VP^{TornN})



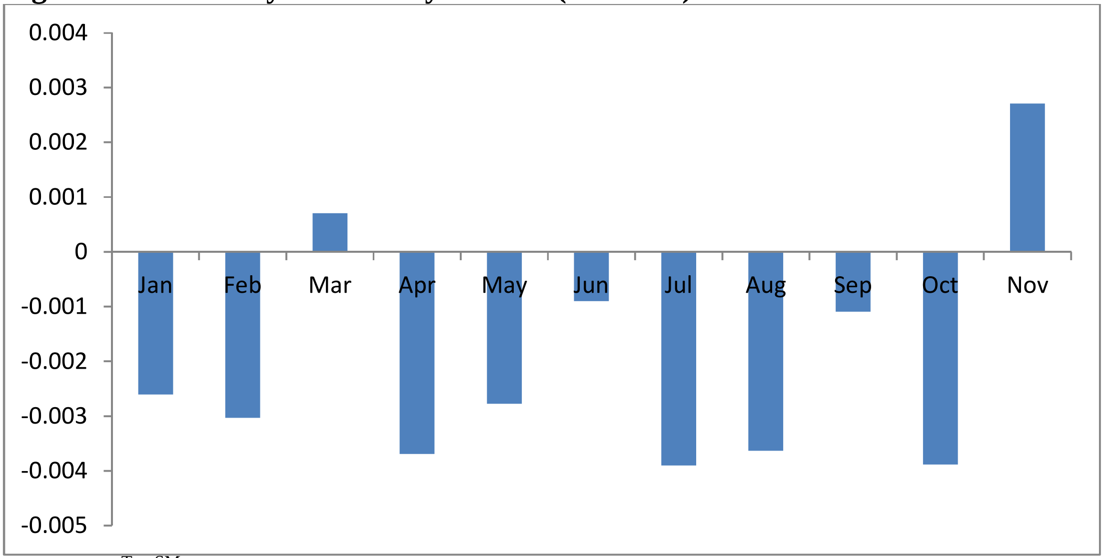
Notes: VP^{TornN} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by Naïve approach.

Figure 3.3.d Monthly Seasonality Pattern (VP^{TornSG})



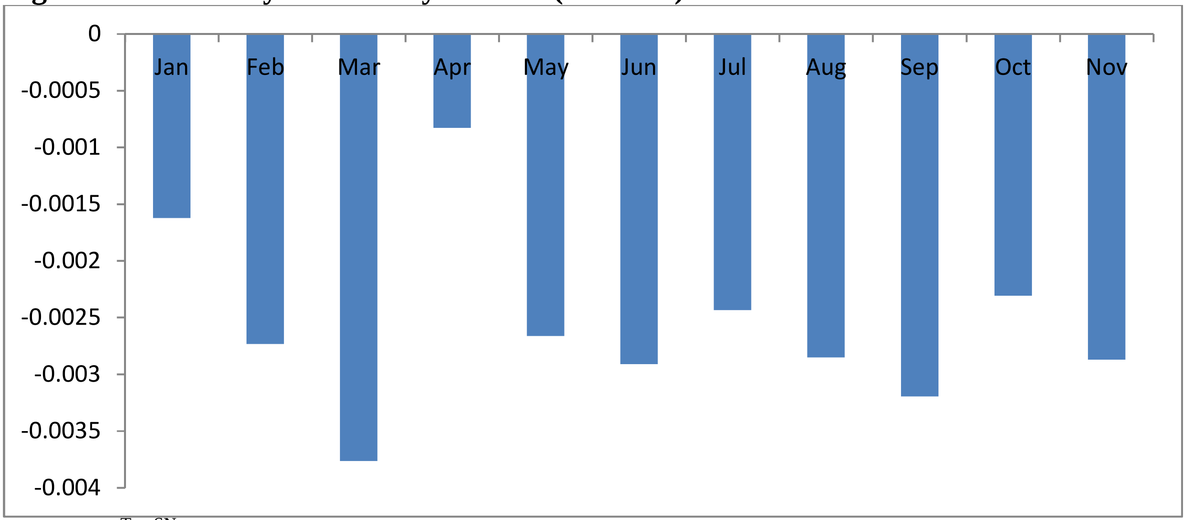
Notes: VP^{TornSG} denotes the aggregate price risk obtained from univariate GARCH model based on Tornqvist price index over commodities.

Figure 3.3.e Monthly Seasonality Pattern (VP^{TornSM})



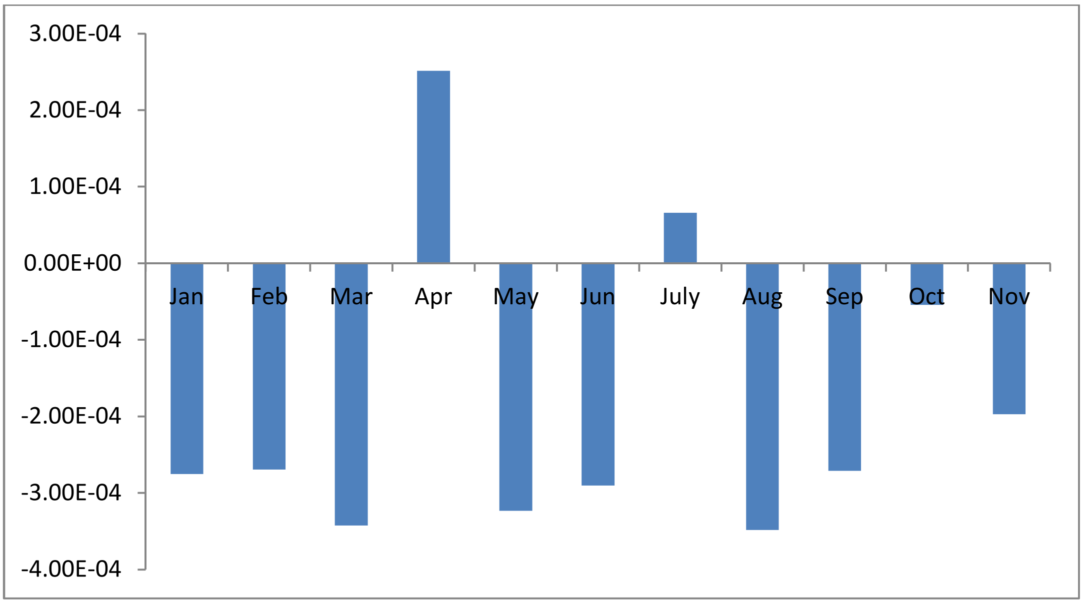
Notes: VP^{TornSM} denotes the aggregate price risk obtained from univariate M Het model based on Tornqvist price index over commodities.

Figure 3.3.f Monthly Seasonality Pattern (VP^{TornSN})



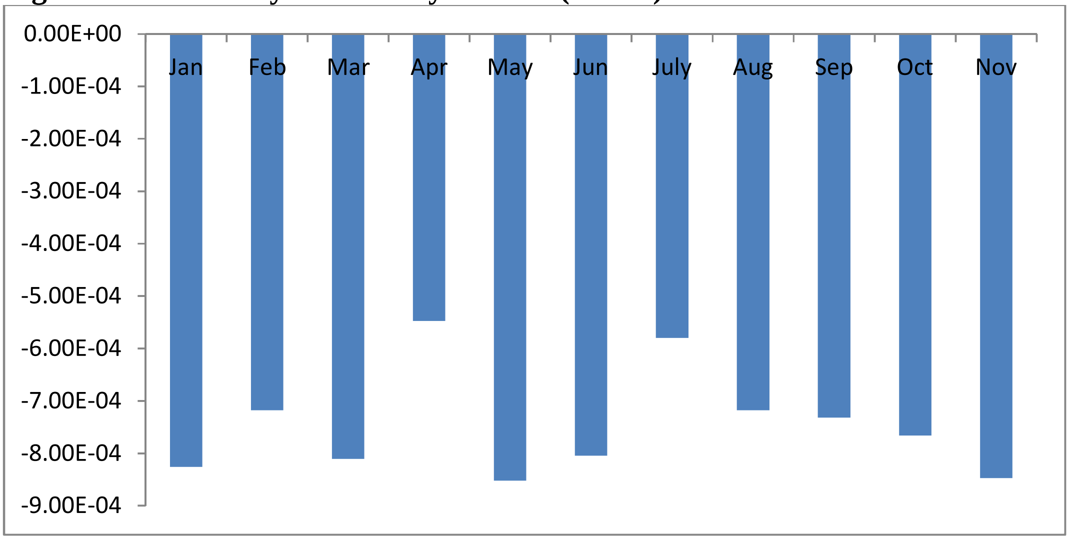
Notes: VP^{TornSN} denotes the aggregate price risk obtained from Naïve approach based on Tornqvist price index over commodities.

Figure 4.1.a Monthly Seasonality Pattern (VarP^r)



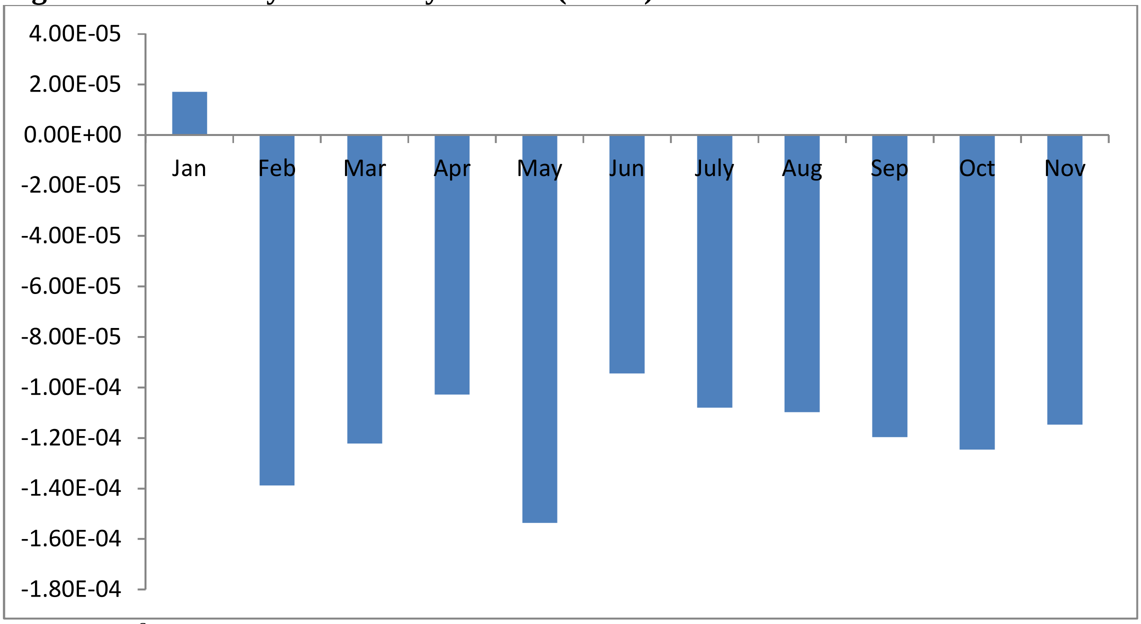
Notes: VarP^r denotes variance of rice price;
Seasonality is estimated from OLS model.

Figure 4.1.b Monthly Seasonality Pattern ($VarP^w$)



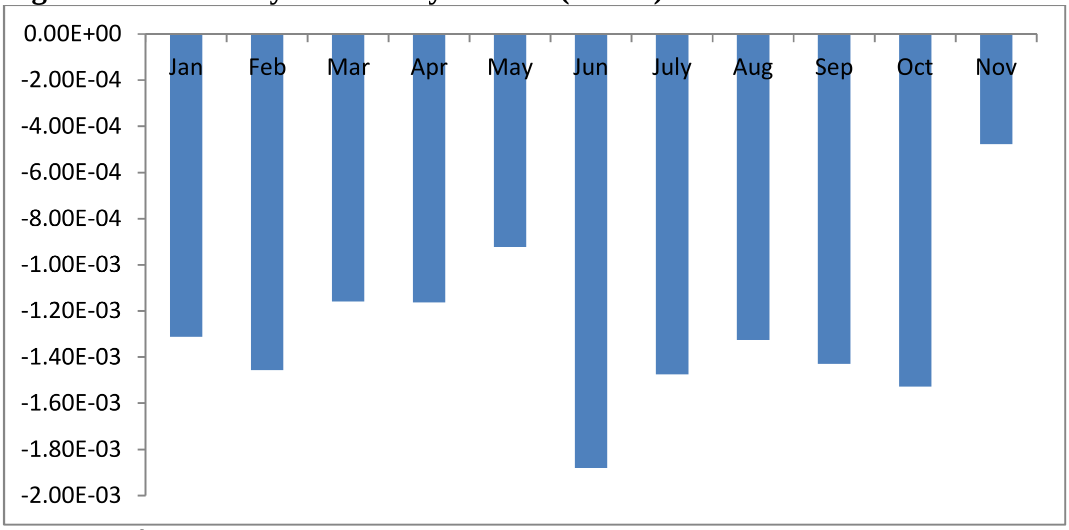
Notes: $VarP^w$ denotes variance of wheat price;
Seasonality is estimated from OLS model.

Figure 4.1.c Monthly Seasonality Pattern (VarP^c)



Notes: VarP^c variance of corn price;
Seasonality is estimated from OLS model.

Figure 4.1.d Monthly Seasonality Pattern ($VarP^s$)



Notes: $VarP^s$ denotes variance of soybeans price;
Seasonality is estimated from OLS model.

APPENDIX TWO

Measuring Price Risk for Multiple Commodities Using Multivariate Diagonal BEKK GARCH Models

Chapter 2 of the thesis focuses on the two-step process with the assumption of constant conditional correlation (CCC) for modeling conditional covariances. Here we consider a common alternative to CCC: a diagonal BEKK multivariate GRACH model, which assumes that conditional correlations vary over time. The correlation between an aggregate price risk index based on a diagonal BEKK model and the aggregate price risk index based on two-step CCC multivariate GARCH model (described in Chapter 2) is 0.97. The similarity of aggregate risk indexes supports use of the simpler CCC assumption.

In theory, extending univariate GARCH to general multivariate GARCH is straightforward, following Bollerslev, Engle and Wooldridge (1988). Consider the error process $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t}, ..., \varepsilon_{Nt})^T$ is an N-dimension time series. By convention, we assume that ε_t is conditionally heteroskedastic as:

$$\varepsilon_t = \eta_t H_t^{1/2} \tag{A2.1}$$

where $\varepsilon_t = y_t - \mu_t(y_t)$, η_t follows a multivariate Gaussian distribution with $E(\eta_t) = 0$ and $E\eta_t\eta_t' = I$, and $H_t = \left[h_t^{ij}\right]$ is the $N \times N$ conditional variance-covariance matrix of ε_t

In the multivariate setting, every conditional variance and covariance is a function of all lagged conditional variances and covariances. The general multivariate GARCH (p,q) model of Bollerslev, Engle, and Wooldridge (1988) is:

$$vech(H_t) = c + \sum_{m=1}^{q} Avech(\varepsilon_{t-m}\varepsilon_{t-m}^{\mathrm{T}}) + vech\sum_{n=1}^{p} Bvech(H_{t-n}) \tag{A2.2}$$

In equation (A2.2), the vector c represents deterministic components of the covariances and contains $(N(N+1)/2)^2$ parameters. A and B are parameter matrices with each one containing $(N(N+1)/2)^2$ elements. However, due to the large number of parameters, this model is intractable for empirical research. Alternatively, for empirical work, the diagonal BEKK GARCH model was developed by Baba, Engle, Kraft and Kroner (1990). This multivariate model is commonly estimated in empirical work and assumes non-constant conditional correlations. The diagonal BEKK model defines the coefficient matrices A and B as diagonal matrices. The basic diagonal BEKK GARCH model is specified as:

$$H_t = \Omega\Omega' + \sum_{m=1}^{q} A_m \varepsilon_{t-m}\varepsilon_{t-m}^{\mathrm{T}} A_m^T + \sum_{n=1}^{p} B_n H_{t-n} B_n^T \tag{A2.3}$$

Where A_m, B_n, and Ω are all $N \times N$ parameter matrices, and Ω is a lower triangular matrix.

According to Bollersleve, Engle, and Wooldridge (1998), the main advantage of this model is that the number of parameters decreases to N(N+1)/2+2N while still maintaining the positive definiteness of H_t

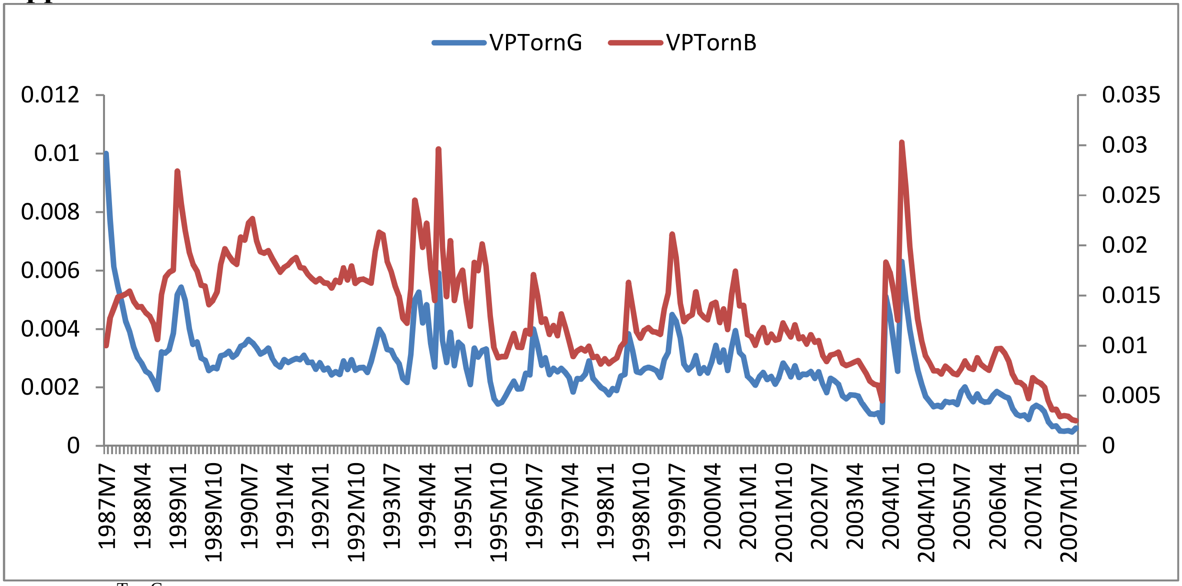
As an alternative to the CCC multivariate GARCH model in Chapter 2, a four price diagonal BEKK model was programmed and estimated using Eviews. The estimated results for diagonal BEKK model under multivariate normal distribution are reported in Table A2.1. In the covariance equation, all coefficients are significant at 1% level except for the coefficient on residuals of soybeans.

An aggregate price risk index using the price variances and covariances estimated from the diagonal BEKK model is also constructed. The correlation between the aggregate price risk index obtained from the BEKK model and the one obtained from 2-step process and univariate GARCH model presented in Chapter Two is 0.97. These two aggregate price risk indexes are plotted in Figure A.2.1. Overall the two aggregate price risk indexes trend together except for the initial period. Furthermore, individual price variances and covariances obtained from the above two approaches are also compared, and results are very similar except for the case of soybeans. Since soybeans production has the lowest value of the four commodities, this explains the similarity of the aggregate price risk indexes. Given the similarity in results, this thesis employs the simple two-step CCC multivariate GARCH model rather than diagonal BEKK.

Table A.2.1: Parameter Estimates of Diagonal BEKK Model for Grain Prices,1987-2007				
Estimation Method: ARCH Maximum Likelihood (Marquardt)				
Covariance specification: Diagonal BEKK				
$P^{RICE} = C(1)+C(2)* P^{RICE} (-1)+C(3)* P^{RICE} (-3)+C(4)* P^{RICE} (-6)$				
$P^{WHEAT} = C(5)+C(6)* P^{WHEAT} (-1)+C(7)* P^{WHEAT} (-2)+C(8)* P^{WHEAT} (-6)$				
$P^{CORN} = C(9)+C(10)* P^{CORN} (-1)+C(11)* P^{CORN} (-2)+C(12)* P^{CORN} (-3)$				
$P^{SOYBEAN} = C(13)+C(14)* P^{SOYBEAN} (-1)+C(15)* P^{SOYBEAN} (-2)+C(16)* P^{SOYBEAN} (-5)$				
	Coefficient	Std. Error	z-Statistic	Prob.
C(1)	0.0084	0.0074	1.1378	0.2552
C(2)	1.1031***	0.0441	25.0121	0.0000
C(3)	-0.0777	0.0612	-1.2692	0.2044
C(4)	-0.0334	0.0363	-0.9217	0.3567
C(5)	0.0111	0.0096	1.1564	0.2475
C(6)	1.2146***	0.0601	20.2254	0.0000
C(7)	-0.2003***	0.0708	-2.8306	0.0046
C(8)	-0.0234	0.0234	-1.0027	0.3160
C(9)	0.0052	0.0046	1.1184	0.2634
C(10)	1.1682***	0.0544	21.4597	0.0000
C(11)	-0.0037	0.0949	-0.0394	0.9685
C(12)	-0.1692***	0.0624	-2.7094	0.0067
C(13)	0.0061	0.0112	0.5473	0.5842
C(14)	1.0510***	0.0610	17.2223	0.0000
C(15)	0.0894	0.0822	1.0866	0.2772
C(16)	-0.1414***	0.0352	-4.0203	0.0001
GARCH = M + A1*RESID(-1)*RESID(-1)'*A1 + B1*GARCH(-1)*B1				
Variance Equation	Coefficient	Std. Error	z-Statistic	Prob.
M(1,1)	0.0001***	0.0000	2.9290	0.0034
M(1,2)	0.0002***	0.0000	3.7539	0.0002
M(1,3)	0.0000***	0.0000	3.3622	0.0008
M(1,4)	0.0001***	0.0000	3.6158	0.0003
M(2,2)	0.0004***	0.0001	3.6010	0.0003
M(2,3)	0.0001***	0.0000	3.7378	0.0002
M(2,4)	0.0001***	0.0000	3.7425	0.0002
M(3,3)	0.0000***	0.0000	3.9071	0.0001
M(3,4)	0.0000***	0.0000	3.7118	0.0002
M(4,4)	0.0001***	0.0000	3.4545	0.0006
A1(1,1)	0.4254***	0.0398	10.6867	0.0000
A1(2,2)	0.2760***	0.0675	4.0887	0.0000
A1(3,3)	0.1792***	0.0278	6.4580	0.0000
A1(4,4)	0.0389	0.0401	0.9686	0.3327
B1(1,1)	0.8889***	0.0226	39.3971	0.0000
B1(2,2)	0.7189***	0.0836	8.5976	0.0000
B1(3,3)	0.9766***	0.0060	161.6897	0.0000
B1(4,4)	0.9988***	0.0023	427.3634	0.0000

Table A.2.1: Parameter Estimates of Diagonal BEKK Model for Grain Prices,1987-2007(Cntd.)				
Log likelihood	1899.865	Schwarz criterion		-14.68516
Avg. log likelihood	1.930757	Hannan-Quinn criter.		-14.97456
Akaike info criterion	-15.16964			
Log likelihood	1899.865	Schwarz criterion		-14.68516
Notes: *** denotes 1% significance level, ** 5% significance level, * 10% significant level.				
In Covariance Equation,1= P^{rice}, 2= P^{wheat}, 3= P^{corn}, and 4= $P^{soybeans}$				
P^{rice} denotes rice price, P^{wheat} denotes wheat price, P^{corn} denotes corn price, and $P^{soybeans}$ denotes soybeans price.				

Figure A.2.1: Plot of Aggregate Price Risk Index Obtained from Two Different Approaches



Notes: VP^{TornG} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by univariate GARCH model; VP^{TornB} denotes aggregate Tornqvist-type price risk index in which risk of individual prices is specified by multivariate diagonal BEKK GARCH model.