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First and Second Order Impacts of Speculation on Commodity Price Volatility

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Abstract : This paper contributes to the debate on the link between speculation and price volatility in two ways. First, a simple CAPM model is used to derive the demand for commodity futures contracts by institutional investors, and this derived demand is then integrated into a simple rational expectations model of a commodity market with a demand for hedging by merchants. Second, a GARCH model is used to measure volatility in the U.S. rice market before and after the introduction of a futures contract for rice in 1994. The theoretical and empirical analysis both demonstrate that speculation results in a first order decrease in commodity price volatility, but part of this decrease will be offset by second order pricing distortions that are caused by institutional speculators.

Résumé: Nous ajoutons de nouveaux éléments au débat sur le lien entre la spéculation et la volatilité des prix. Premièrement, un modèle CAPM est utilisé pour dériver la demande en contrats à terme d'investisseurs institutionnels. Cette demande est ensuite intégrée dans la modélisation d'un marché pour un produit primaire. Nous supposons que les participants dans ce marché ont des attentes rationnelles, incluant des marchands qui ont une demande de couverture. Deuxièmement, un modèle de type GARCH est spécifié pour mesurer la volatilité sur le marché américain du riz, avant et après la première émission de contrats à terme pour le riz en 1994. Les analyses théorique et empirique ont démontré que la spéculation entraîne une diminution de premier rang de la volatilité des prix, mais qu'une partie de cette diminution est contrée par des distorsions de deuxième rang attribuables aux spéculateurs institutionnels.

Keywords: Commodity Futures, Speculation, Price Volatility, CAPM, Rice.

JEL classification: Q11, Q14, Q18

1 Introduction

In recent years there has been a great deal of debate about speculation as a cause of excess price volatility in agricultural commodity markets. At the center of this debate is the link between price volatility and the growing dominance of futures contracts held by large institutional investors such as hedge and index funds. Masters and White [2008] noted that between 2003 and 2008 the amount of money allocated to trading strategies which are designed to replicate a commodity index (includes energy) has risen from about $13 billion to over $300 billion. During this same period the prices of the 25 underlying commodities that comprise the index have risen on average by about 200 percent.

While such evidence that institutional investors were responsible for the price surge is compelling, there is no clear consensus by economists on this issue. For example, von Braun and Torero [2009] and Gilbert [2010] include the flow of speculative capital from institutional investors in their list of reasons for the 2006 - 2008 price bubble. Others have argued that the apparent link between speculation and commodity price volatility is based on faulty economic logic [Irwin, Sanders, and Merrin, 2009] and that standard fundamentals of supply, demand and commodity stocks still provide the best explanation for current commodity price volatility [Wright, 2011]. The various arguments concerning institutional investors and commodity price volatility are summarized by [Hailu and Weersink, 2010].

The purpose of this paper is to enter the debate by modeling both theoretically and empirically the link between speculation and commodity price volatility. The theoretical results are established by combining a simple capital asset pricing model (CAPM) of institutional speculators who hold commodity futures to diversity their personal portfolios with a simple rational expectations model of a commodity market with hedging merchants and professional speculators. An important assumption is that institutional speculators also have rational expectations, which implies that the price volatility results cannot be attributed to incomplete information or irrational decision making. Rather than attempting to defend the validity of this assumption, it is simply noted that it is important to first understand the relationship between speculation and price volatility in an environment where traders are fully informed and rational before attempting to model pricing outcomes that are due to misinformation and irrational behaviour.[1]

Regarding the theoretical analysis, speculation is shown to cause a first order decrease in price volatility because rational speculation, both professional and institutional, generates more accurate information, which in turn leads to more efficient storage decisions by merchants. However, some of the first order decrease in price volatility can be lost because of a second order pricing distortion that results from the institutional speculator's willingness to pay a premium price to enter a long futures contract and a corresponding increase in the amount stored by merchants. The net impact of speculation on price volatility therefore depends on the specific characteristics of the pool of speculators. For example, speculation will cause a smaller reduction in price volatility the higher the fraction of institutional speculators within the total pool of speculators and the higher their degree of risk aversion.

The second part of this paper uses data from the U.S. rice market to examine the link between speculation and price volatility. There are two general approaches to this type of analysis. The first approach follows Working [1960], Gray [1963] and Johnson [1973]), who examined the link between speculation and price volatility by comparing cash price volatility before and after the introduction of a commodity futures market. This approach is simple to implement, but it does not specifically isolate the impact of institutional speculation on commodity price volatility. A more recent method for examining the link between speculation and price volatility is to regress price on a measure of speculative activity such as the ratio of volume and open interest [Robles, Torero, and von Braun, 2009].

This current analysis uses the earlier approach of measuring volatility before and after the introduction of a futures market. However, instead of using a fixed measure of price volatility such as standard deviation, the analysis follows Antoniou and Holmes [1995] and Yang, Haigh,

[1]Masters and White [2008] and others who advocate market regulation due to excessive speculation are likely to disagree with the assumption that institutional speculators are fully rational. Indeed, when describing index traders Masters and White [2008] note that "their buying and trading has nothing to do with the supply and demand fundamentals of any single commodity. They pour money into commodities futures to diversify their portfolios, hedge against inflation or bet against the dollar (Executive Summary)."

and Leatham [2001] by estimating a generalized autoregressive conditional heteroskedasticity (GARCH) model with an event dummy variable. The GARCH model is desirable in this context because it is able to control for other sources of price volatility when the relationship between speculation and price volatility is estimated. The U.S. rice market is well suited for the current analysis for two reasons. First, rice contracts began trading on the Chicago Board of Trade (CBOT) in 1994, and so a moderately-long time series of data is available before and after the introduction of the futures market. Second, there is no futures trading for rice outside of the U.S., and so the world price of rice can be used to control for sources of volatility which are independent of speculation in a centralized market.

The GARCH model that is used in this analysis does not solve the problem of isolating the specific effects of institutional speculation on price volatility. Nevertheless, a comparison of the plot of GARCH volatility estimates and non-commercial open interest clearly shows an apparent connection between institutional speculation and commodity price volatility in the U.S. rice market. Specifically, the plot reveals that futures trading as a whole has reduced price volatility because the large volatility spikes which periodically appeared before the introduction of the futures market have not reappeared since 1994. However, the plot also reveals that high frequency, low magnitude price volatility roughly coincides with the period of rapid growth in non-commercial speculation. This observation is consistent with the theoretical finding that speculation is expected to reduce price volatility, but this reduction will be partially offset by institutional trading pricing distortions.

Discussion about the link between speculation and price volatility can be traced back to Friedman [1953] (p. 175). Friedman was commenting on the popular view that "amateur" speculators take a price decrease as a signal of further decreases and a price increases as a signal of further increases. According to this view amateur speculation will add to price volatility because speculators will take short positions when prices are decreasing and long positions when prices are increasing. Friedman disagreed with this popular view by noting that pursuing such a strategy would result in speculators losing money on average. Moreover, "clever" speculators could profit from the actions of the misinformed speculators, and this type of arbitrage would eliminate the price volatility that is caused by misinformed speculation. Powers [1970] and Cox [1976] demonstrate both theoretically and empirically that futures trading increases the flow of information to speculators about market fundamentals. Powers shows the the speculative activity of futures traders reduces the random component of price variance. In Cox's model speculation increases the information content of prices, and so speculation can never be destabilizing. Hart and Kreps [1986] take an opposite view and argue that in a market where rational agents have access to identical information and history, speculation may increase price volatility. Specifically, rational speculators base their decision to enter the market in the current period on the probability that certain changes will occur in fundamentals in the next period. If the desired changes do not take place, the actions of many speculators unwinding their positions in the next period will lead to higher volatility.

Irwin et al. [2009] reject the arguments that unrestricted speculation by institutional investors is the cause of recent price spikes in agricultural commodity markets. First, they note that at a given price level an arbitrarily large number of contracts can trade without influencing the price. The reason is that for every long position there must be a short position, and so speculators who do not deal with the physical commodity are essentially engaged in a zero sum game. Information about supply and demand fundamentals may change, and if this change causes the price and number of contracts traded to increase, then there will exists a statistical correlation, but such a correlation does not imply causation. Second, prices are discovered in futures markets for efficiency reasons, but it is the supply and demand attributes in the cash market that determine long run equilibrium prices. Thirdly, it is the delivery option associated with each futures contract that ties the cash and futures markets together. Since institutional speculators never make or take delivery of the commodity there should be no link between the actions of institutional speculators and price in the cash market.

In the next section the basic structure of the theoretical model is laid out. Section 3 is used to present and discuss the formal theoretical results. The empirical analysis is the topic of Section 4. Concluding comments are provided in Section 5.

2 Model Overview

The theoretical analysis involves merging a simple CAPM model of securities investment that defines the demand for futures contracts by institutional investors with a simple two-period rational expectations model of price discovery in a closed market with production certainty and demand uncertainty. In the rational expectations model merchants own commodity stock at the beginning of period 1 and choose how much to sell in the period 1 cash market and how much to store for sale in the period 2 cash market. Period 1 sales equal starting aggregate inventories, Z, which is exogenous, minus aggregate storage, S, which is endogenous. Period 2 sales equal aggregate storage, S, because by assumption there is no production in period 2. The period 1 cash price is assumed to be a linear function of aggregate period 1 sales: $P_1 = \bar{\alpha} - (Z - S)$.[2] The period 2 cash price, which is a linear function of period 2 sales, can be expressed as $\tilde{P}_2 = \tilde{\alpha} - S$ where the random intercept term, $\tilde{\alpha}$, takes on a value of either α_L or α_H. Assume $\alpha_L < \alpha_H$ and $(\alpha_L + \alpha_H)/2 = \bar{\alpha}$. The latter restriction implies that if α_L and α_H are equally likely then the expected demand in period 2 is the same as the certain demand in period 1. The probabilities which govern the period 2 outcome for $\tilde{\alpha}$ are discussed below.

Speculation is incorporated into the analysis by assuming that it improves the accuracy of the period 2 price forecast. Without speculation merchants operate with a non-informative probability distribution for $\tilde{\alpha}$ (i.e., α_L and α_H are equally likely). In contrast, if speculators actively trade in a centralized commodity futures market then as a result of the detailed information gathering an informative signal, I, is randomly generated at the beginning of period 1. Assume $I \in \{\text{"Bearish"}, \text{"Bullish"}\}$ with equal probability and also assume that the random outcome for I determines the probability distribution for $\tilde{\alpha}$. A bearish outcome shifts probability weight toward α_L and a bullish outcome shifts probability weight toward α_H. The solution to the market outcome without speculation is easily nested in the solution to the market outcome with speculation (more details below). Thus, the majority of the analysis is devoted to deriving the market

[2] Restricting the slope of the demand equation to minus one is not restrictive because any linear demand function with a slope different than minus one can be converted to one with a slope of minus one by adjusting the values of the intercept and the quantity unit.

outcome with speculation and only in the final stages of the analysis is the no-speculation case explicitly considered.

Both merchants and speculators form expectations rationally. Specifically, both groups rationally anticipate the supply of storage function which describes how merchants collectively allocate stocks between periods 1 and 2. Merchants are assumed to fully hedge their stored commodity. Moreover, one unit of the stored commodity is assumed to correspond to a one unit futures contract. This pair of assumptions implies that the supply of storage function can also be interpreted as the merchants' demand for short futures. The futures market achieves an equilibrium when the futures price, f, is such that the merchants' demand for short futures is equal to the speculators' demand for long futures. Merchants and speculators rationally anticipate f as a function of the bearish or bullish information outcome that is revealed to traders at the beginning of period 1.

Merchants operate with an upward sloping aggregate supply of storage schedule. Such a schedule will emerge if individual competitive merchants each have a fixed marginal cost of storage, and the level of marginal cost varies across merchants. Without loss in generality it is more convenient to assume a single representative merchant with an increasing marginal cost of storage given by $-\phi_0/\phi_1 + (1/\phi_1)S$. Within this equation the parameters ϕ_0 and ϕ_1 are assumed to take on a negative value and positive value, respectively. The supply of storage schedule for the representative merchant, which also represents the merchant's demand for short futures, can be expressed as $S = \phi_0 + \phi_1(f - P_1)$. Within this equation $f - P_1$ represents the returns to storage because the short futures position guarantees the merchant a price f in period 2 and P_1 is a measure of foregone revenue from storing rather than selling in period 1.

There are two types of speculators, professional and institutional. For both groups the expected returns to a long position is $E(\tilde{P}_2) - f$ because when the long futures contract is offset in period 2 the futures offset price will equal the cash price, $\tilde{P}_2$. Professional speculators are assumed to be risk neutral, numerous and highly competitive. Consequently, this group has a perfectly elastic demand for long futures at price $f = E(\tilde{P}_2)$. As is shown in the next section, institutional speculators have a downward sloping demand for long futures. Thus, aggregate demand for the two groups is a downward sloping schedule for $f > E(\tilde{P}_2)$ and a perfectly elastic schedule for $f = E(\tilde{P}_2)$. In scenario A professional speculators are the dominant group, which implies that the merchant's supply of short futures schedule intersects the aggregate demand for long futures schedule where demand is perfectly elastic at price $f = E(\tilde{P}_2)$. In scenario A institutional speculators participate in the market but their actions are irrelevant for price discovery because the equilibrium value of f does not deviate from $E(\tilde{P}_2)$. In scenario B institutional speculators are the dominant group, which implies that the merchant's supply of short futures schedule intersects the aggregate demand for long futures schedule where demand is downward sloping. In scenario B the actions of institutional speculators are highly relevant because the equilibrium value of f is above $E(\tilde{P}_2)$ and it will depend on the specific preferences of speculators. The main results of the analysis are generated by comparing price volatility for scenarios A and B.[3]

2.1 Institutional Speculators

The purpose of this section is to derive the demand for long futures by institutional speculators. Similar to the case of merchants, the demand for long futures is derived for a single representative speculator rather than for the group as a whole. The demand for long futures by the risk averse institutional speculator is downward sloping. However, as the speculator's degree of risk aversion approaches zero this demand schedule becomes perfectly elastic at price $f = E(\tilde{P}_2)$. This means that a simple adjustment of the institutional speculator's risk aversion parameter allows the corresponding demand function to represent either scenario A (professional speculators dominate) or scenario B (institutional speculators dominate).

The feature which distinguishes an institutional speculator from a professional speculator is a personal financial portfolio. The non-commodity portfolio of the institutional speculator is

[3]In real world markets speculators take both long and short positions. Indeed, it is the demand for short and long positions by speculators with heterogeneous beliefs and sources of information that results in efficient price discovery. This analysis is simplified by assuming that speculators first establish a demand forecast (i.e., bearish or bullish) and then take a position on the long side of the market to facilitate hedging by merchants. The model could be generalized to allow for long and short positions by speculators, but little additional insight into the issue of price volatility would be gained by this generalization.

assumed to generate random period 2 profits $\tilde{\omega}$ where $\tilde{\omega} = \omega$ with 50 percent probability and $\tilde{\omega} = -\omega$ with 50 percent probability. This zero expected profit assumption is not important for the analysis and should be viewed as a convenient normalization. The institutional speculator can diversify by adding to the non-commodity portfolio X units of long commodity futures. Period 2 profits generated by the full portfolio, $\tilde{\pi}$, can be expressed as $\tilde{\pi} = \tilde{\omega} + (\tilde{P}_2 - f)X$ where $\tilde{P}_2 = \alpha_L - S^*$ in a low period 2 demand state and $\tilde{P}_2 = \alpha_H - S^*$ in a high period 2 demand state. The variable S^* represents the rationally calculated level of commodity storage from period 1 (more details below).

The speculator chooses X to maximize a standard mean-variance utility function, which can be expressed as $U = E(\tilde{\pi}) - \lambda Var(\tilde{\pi})$. Recalling that the expected value of $\tilde{\omega}$ is zero, the speculator will choose a positive value for X if $E(\tilde{P}_2) - f > 0$. However, even if $E(\tilde{P}_2) - f$ takes on a non-positive value, the speculator may still choose a positive value for X provided that $Var(\tilde{\pi})$ is a decreasing function of X for a range of X values. For this outcome to emerge it must be the case that $\tilde{\omega}$ and $\tilde{P}_2$ are negatively correlated, which is an assumption that is maintained for the remainder of this analysis.[4]

To proceed with the analysis it is necessary to specify the joint probability distribution for $\tilde{\omega}$ and $\tilde{\alpha}$. The marginal distribution for $\tilde{\alpha}$ depends on the outcome of the period 1 information state variable, I (i.e., whether speculators are bearish or bullish about period 2 demand). Assume $\tilde{\alpha} = \alpha_L$ with probability $\frac{1}{2} + \epsilon$ and $\tilde{\alpha} = \alpha_H$ with probability $\frac{1}{2} - \epsilon$ in a bearish information state. Conversely, assume $\tilde{\alpha} = \alpha_L$ with probability $\frac{1}{2} - \epsilon$ and $\tilde{\alpha} = \alpha_H$ with probability $\frac{1}{2} + \epsilon$ in a bullish information state. The parameter $\epsilon \in (0, \frac{1}{2})$ is a measure of the quality of the period 1 information signal. To specify the marginal probability distribution for $\tilde{\alpha}$ more succinctly assume that $\tilde{\alpha} = \alpha_L$ with probability $\frac{1}{2} - \hat{\epsilon}$ and $\tilde{\alpha} = \alpha_H$ with probability $\frac{1}{2} + \hat{\epsilon}$ where $\hat{\epsilon} = \epsilon$ in a bear information state and $\hat{\epsilon} = -\epsilon$ in a bull information state.

[4] Masters and White [2008], Hailu and Weersink [2010] and others have noted that a key reason why institutional speculators hold commodity futures in their portfolio is because commodity futures represent a unique asset class and therefore provide portfolio diversification. In this simple model with only two assets a negative correlation of asset returns is necessary to achieve diversification. The strong assumption of negative correlation could be relaxed if a more general multi-asset CAPM was used to derive the demand for futures contracts because then a less-than-average positive correlation (versus a negative correlation) is sufficient to achieve diversification.

The joint probability distribution for $\tilde{\omega}$ and $\tilde{\alpha}$ is presented in Table 1. The marginal distributions for these two variables are as defined above. The parameter $\theta \in (0, \frac{1}{2})$ creates the desired negative correlation by shifting probability weight away from the $(-\omega, \alpha_L)$ and (ω, α_H) outcomes and towards the $(-\omega, \alpha_H)$ and (ω, α_L) outcomes. Table 1, together with the profit function for the speculator, $\tilde{\pi} = \tilde{\omega} + (\tilde{P}_2 - f)X$, and the period 2 pricing equation, $\tilde{P}_2 = \tilde{\alpha} - S^*$, can now be used to derived expressions for expected profits and the variance of profits for the institutional speculator. After simplification, the desired expressions can be written as

$$E(\tilde{\pi}) = (\bar{\alpha} - S^* - f)X - (\alpha_H - \alpha_L)\hat{\epsilon}X \tag{1}$$

and

$$Var(\tilde{\pi}) = \tag{2}$$

$$(\tfrac{1}{4} + \tfrac{1}{2}\hat{\epsilon} - \tfrac{1}{2}\theta)[(\alpha_H - \alpha_L)(\hat{\epsilon} - \tfrac{1}{2}X) - \omega]^2 + (\tfrac{1}{4} - \tfrac{1}{2}\hat{\epsilon} + \tfrac{1}{2}\theta)[(\alpha_H - \alpha_L)(\hat{\epsilon} + \tfrac{1}{2}X) - \omega]^2 +$$
$$(\tfrac{1}{4} + \tfrac{1}{2}\hat{\epsilon} + \tfrac{1}{2}\theta)[(\alpha_H - \alpha_L)(\hat{\epsilon} - \tfrac{1}{2}X) + \omega]^2 + (\tfrac{1}{4} - \tfrac{1}{2}\hat{\epsilon} - \tfrac{1}{2}\theta)[(\alpha_H - \alpha_L)(\hat{\epsilon} + \tfrac{1}{2}X) + \omega]^2$$

Keep in mind that $\hat{\epsilon} = \epsilon$ if the period 1 information state is bearish and $\hat{\epsilon} = -\epsilon$ if the information state is bullish.

		Demand Variable, $\tilde{\alpha}$		
		α_L	α_H	Marginal
Other Wealth	$-\omega$	$\frac{1}{4} + \frac{1}{2}\hat{\epsilon} - \frac{1}{2}\theta$	$\frac{1}{4} - \frac{1}{2}\hat{\epsilon} + \frac{1}{2}\theta$	$\frac{1}{2}$
Variable, $\tilde{\omega}$	ω	$\frac{1}{4} + \frac{1}{2}\hat{\epsilon} + \frac{1}{2}\theta$	$\frac{1}{4} - \frac{1}{2}\hat{\epsilon} - \frac{1}{2}\theta$	$\frac{1}{2}$
	Marginal	$\frac{1}{2} + \hat{\epsilon}$	$\frac{1}{2} - \hat{\epsilon}$	
Note: $\hat{\epsilon} = \epsilon$ in bear market and $\hat{\epsilon} = -\epsilon$ in bull market				

Table 1: Joint Probabilities for Institutional Speculator

The next step is to substitute equations (1) and (2) into the speculator's expected utility function, which is given by $U = E(\tilde{\pi}) - \lambda Var(\tilde{\pi})$. After making this substitution and maximizing expected utility with respect to X, the following expression emerges:

$$X^* = \frac{4}{(\alpha_H - \alpha_L)^2}\left[\frac{\bar{\alpha} - S^* - f - (\alpha_H - \alpha_L)\hat{\epsilon}}{\lambda} + (\alpha_H - \alpha_L)^2\hat{\epsilon}^2 + (\alpha_H - \alpha_L)\omega\right] \tag{3}$$

Equation (3) represents the demand for long futures by the institutional speculator. To make the expression more explicit note that $E(\tilde{P}_2) = (\frac{1}{2} + \hat{\epsilon})(\alpha_L - S^*) + (\frac{1}{2} - \hat{\epsilon})(\alpha_H - S^*)$, which reduces to $E(\tilde{P}_2) = \bar{\alpha} - S^* - (\alpha_H - \alpha_L)\epsilon$. After substituting this expression into equation (3) the revised demand schedule can be written as

$$X^* = \gamma_0 - \gamma_1 \left(f - E(\tilde{P}_2) \right) \tag{4}$$

where $\gamma_0 = 4[\hat{\epsilon}^2 + \omega/(\alpha_H - \alpha_L)]$ and $\gamma_1 = 4/[(\alpha_H - \alpha_L)^2 \lambda]$. The positive values for γ_0 and γ_1 ensure the demand for long futures by institutional investors is downward sloping and positive when $f = E(\tilde{P}_2)$. When the demand equation is expressed in inverse form, $f - E(\tilde{P}_2) = \gamma_0/\gamma_1 - (1/\gamma_1)X$, it is easy to see that demand becomes perfectly elastic at price $f = E(\tilde{P}_2)$ as the degree of risk aversion, λ, approaches zero.

The downward sloping demand for long futures by institutional speculators is a central feature of this analysis. Demand is downward sloping because of the classic CAPM risk-return tradeoff. Specifically, with fair pricing given by $f = E(\tilde{P}_2)$ the demand for futures is positive because holding long futures reduces the variance of the overall portfolio return, and such a reduction is valuable for a risk averse investor. If the value of $f - E(\tilde{P}_2)$ increases above zero then the expected return on the long position becomes negative and this will reduce demand for long futures. For a sufficiently large positive value for $f - E(\tilde{P}_2)$ demand for long positions becomes negative, which is equivalent to the institutional speculator demanding short contracts.

2.2 Equilibrium Storage and Prices

In order to solve for the equilibrium futures price, f, which ensures that the supply of storage (equivalent to the demand for short futures), $S = \phi_0 + \phi_1(f - P_1)$, is equal to the demand for long futures, $X^* = \gamma_0 - \gamma_1 \left(f - E(\tilde{P}_2) \right)$, it is necessary to express the former equation in terms of $E(\tilde{P}_2)$ rather than P_1. To make this conversion, substitute $S = \phi_0 + \phi_1(f - P_1)$ into the expression for $E(\tilde{P}_2)$, which was derived above and written as $E(\tilde{P}_2) = \bar{\alpha} - S^* - (\alpha_H - \alpha_L)\epsilon$. The resulting equation can be expressed as

$$f - P_1 = \left[\frac{\bar{\alpha} - \phi_0 - (\alpha_H - \alpha_L)\hat{\epsilon}}{\phi_1} + \frac{f - E(\tilde{P}_2)}{\phi_1} - \frac{P_1}{\phi_1} \right] \frac{\phi_1}{\phi_1 + 1} \tag{5}$$

Now substitute $S = \phi_0 + \phi_1(f - P_1)$ into the expression for first period price, $P_1 = \bar{\alpha} - (Z - S)$, and solve for P_1. After substituting the resulting expression for P_1 into equation (5) the revised version of equation (5) can be expressed as

$$f - P_1 = \frac{Z - 2\phi_0 - \hat{\epsilon}(\alpha_H - \alpha_L)}{1 + 2\phi_1} + \frac{f - E(\tilde{P}_2)}{1 + 2\phi_1} \tag{6}$$

Finally, substitute equation (6) into the supply of storage equation, $S = \phi_0 + \phi_1(f - P_1)$, and rearrange to obtain an expression for the supply of storage (equivalent to demand for short futures) which is written as a function of $f - E(\tilde{P}_2)$ rather than $f - P_1$:

$$S^* = \frac{\phi_0 + \phi_1 Z - \phi_1 \hat{\epsilon}(\alpha_H - \alpha_L)}{1 + 2\phi_1} + \frac{\phi_1}{1 + 2\phi_1}\left(f - E(\tilde{P}_2)\right) \tag{7}$$

The remaining step for deriving an expression for equilibrium f is to set the demand for short futures by merchants, which is given by equation (7), equal to the demand for long futures by speculators. Recall that in scenario A professional speculators dominate, in which case the demand for long futures is perfectly elastic at price $f = E(\tilde{P}_2)$. In scenario B institutional speculators dominate, in which case the demand for long futures is given by equation (4). For scenario B if equations (4) and (7) are set equal the resulting expression can be solved for the equilibrium value of the $f - E(\tilde{P}_2)$ price gap:

$$f - E(\tilde{P}_2) = \frac{(1 + 2\phi_1)\gamma_0 - \phi_0 - \phi_1 Z + \phi_1 \hat{\epsilon}(\alpha_H - \alpha_L)}{(1 + 2\phi_1)\gamma_1 + \phi_1} \tag{8}$$

After substituting equation (8) back into equation (4) the following expression emerges for the equilibrium level of storage for scenario B (equivalent to the equilibrium volume of traded futures contracts):

$$S^* = X^* = \frac{\phi_1 \gamma_0 + \gamma_1 \left(\phi_0 + \phi_1 Z - \phi_1 \hat{\epsilon}(\alpha_H - \alpha_L)\right)}{(1 + 2\phi_1)\gamma_1 + \phi_1} \tag{9}$$

It is important to note that equation (9) is relevant for both the case of a bear market ($\hat{\epsilon} = \epsilon$) and a bull market ($\hat{\epsilon} = -\epsilon$)

Now consider scenario A where professional speculators dominate and the demand for long futures is perfectly elastic at price $f = E(\tilde{P}_2)$. The easiest way to derive an expression for equilibrium f and S for this case is to use the scenario B analysis with the assumption of risk neutrality (i.e., $\lambda = 0$). The reason for this is that the demand for long futures with scenario B is given by $X^* = \gamma_0 - \gamma_1[f - E(\tilde{P}_2)]$ where $\gamma_1 = 4/[(\alpha_H - \alpha_L)^2\lambda]$. Thus, $\lambda \to 0$ implies $\gamma_1 \to \infty$, which in turn implies a perfectly elastic demand for long futures at price $f = E(\tilde{P}_2)$. It now follows that equilibrium storage for scenario A is given by equation (9) with $\gamma_1 \to \infty$.

3 Theoretical Results

The theoretical model is intended to shed light on how price variability is impacted by speculation. For this study price variability is defined as the mean squared deviation (MSD) of first and second period price around respective benchmark values. The MSD measures for the two periods are added together to obtain a total measure of price variability. The pricing benchmarks are the corresponding prices that would exist in the absence of demand uncertainty. For the remainder of this analysis the "No" subscript is used to identify the benchmark prices.

It is appropriate to measure MSD before the period 1 information state is revealed. Recall that period 1 information may be bearish or bullish with equal probability. Also recall that with bearish information, prices are low due to low period 2 demand with probability $\frac{1}{2} + \epsilon$ and prices are high due to high period 2 demand with probability $\frac{1}{2} - \epsilon$. The opposite is true with bullish information. The relevant expression for MSD can therefore be written as

$$\begin{aligned} MSD = \frac{1}{2}\left[(P_1^{Bear} - P_1^{No})^2 + (\tfrac{1}{2} + \epsilon)(P_2^{L(Bear)} - P_2^{No})^2 + (\tfrac{1}{2} - \epsilon)(P_2^{H(Bear)} - P_2^{No})^2\right] \\ \frac{1}{2}\left[(P_1^{Bull} - P_1^{No})^2 + (\tfrac{1}{2} - \epsilon)(P_2^{L(Bull)} - P_2^{No})^2 + (\tfrac{1}{2} + \epsilon)(P_2^{H(Bull)} - P_2^{No})^2\right] \end{aligned} \tag{10}$$

Table 2 shows the various price deviations which are required to formally analyze equation (10). The expression for S^{No} is given by equation (9) with $\hat{\epsilon} = 0$.[5] If the reduced expressions in the third column of Table 2 are substituted into equation (10) and the resulting equation simplified, the following equation for MSD emerges:

$$MSD = (S^{Bear} - S^{No})^2 + (S^{Bull} - S^{No})^2 - (S^{Bull} - S^{Bear})^2(\alpha_H - \alpha_L)\epsilon + \tfrac{1}{4}(\alpha_H - \alpha_L)^2 \tag{11}$$

[5] With $\hat{\epsilon} = 0$ the expected value of $\tilde{\alpha}$ is $\bar{\alpha}$ and period 2 expected inverse demand is $P = \bar{\alpha} - S$. In the absence of uncertainty, period 2 inverse demand is also given by $P = \bar{\alpha} - S$.

To measure price volatility which can be attributed to speculation it is necessary to subtract from equation (11) the level of price volatility in the absence of speculation. Earlier it was assumed that no speculation implies a non-informative probability distribution for $\tilde{\alpha}$ (i.e., α_H and α_L are equally likely). Setting $\hat{\epsilon} = 0$ in the model with speculation is equivalent to assuming a model with no speculation because $\hat{\epsilon} = 0$ implies equal probabilities for α_H and α_L. Using equation (9) it is easy to verify that $\hat{\epsilon} = 0$ implies $S^{Bear} = S^{Bull} = S^{No}$. This restriction, together with equation (11), implies $MSD = \frac{1}{4}(\alpha_H - \alpha_L)^2$ for the case of no speculation. This being the case, price volatility which can be attributed to speculation (denoted Δ) can be obtained by subtracting $\frac{1}{4}(\alpha_H - \alpha_L)^2$ from equation (11):

$$\Delta = (S^{Bear} - S^{No})^2 + (S^{Bull} - S^{No})^2 - (S^{Bull} - S^{Bear})^2(\alpha_H - \alpha_L)\epsilon \tag{12}$$

Price Deviation	Explicit Expression	Reduced Expression
$P_1^{Bear} - P_1^{No}$	$\bar{\alpha} - Z + S^{Bear} - (\bar{\alpha} - Z + S^{No})$	$S^{Bear} - S^{No}$
$P_2^{L(Bear)} - P_2^{No}$	$\alpha_L - S^{Bear} - (\bar{\alpha} - S^{No})$	$S^{No} - S^{Bear} - (\bar{\alpha} - \alpha_L)$
$P_2^{H(Bear)} - P_2^{No}$	$\alpha_H - S^{Bear} - (\bar{\alpha} - S^{No})$	$S^{No} - S^{Bear} + (\alpha_H - \bar{\alpha})$
$P_1^{Bull} - P_1^{No}$	$\bar{\alpha} - Z + S^{Bull} - (\bar{\alpha} - Z + S^{No})$	$S^{Bull} - S^{No}$
$P_2^{L(Bull)} - P_2^{No}$	$\alpha_L - S^{Bull} - (\bar{\alpha} - S^{No})$	$S^{No} - S^{Bull} - (\bar{\alpha} - \alpha_L)$
$P_2^{H(Bull)} - P_2^{No}$	$\alpha_H - S^{Bull} - (\bar{\alpha} - S^{No})$	$S^{No} - S^{Bull} + \alpha_H - \bar{\alpha}$

Table 2: Expressions for Price Deviation Variables

The sign of equation (12) is central to the analysis. A negative value implies the actions of speculators decrease price volatility, whereas a positive sign implies speculation increases price volatility. Using equation (12) the following results can now be established.

Result 1. *In scenario A where the market is dominated by professional speculators with a perfectly elastic demand for long futures at price $f = E(\tilde{P}_2)$, price volatility is lower with versus without speculation.*

Proof. See the Appendix for the proof of Result 1 and all remaining results. □

Result 1 is expected because professional speculation provides a price forecast which allows merchants to make more efficient storage decisions (i.e., store less when speculators are bearish and store more when speculators are bullish). In more general terms, competitive speculation in centralized futures markets ensures all available information is reflected in current prices and efficient price discovery in turn leads to an efficient allocation of resources [Carter, 1999]. The efficiency value of price forecasts is also well known in the general literature on the informational role of prices (see, for example, Grossman [1989]).

Result 2. *In scenario B where the market is dominated by institutional speculators with a downward sloping demand for long futures, a higher degree of risk aversion results in higher demand for long futures by speculators, which in turn results in a higher level of price volatility.*

In scenario B the equilibrium value of f is above $E(\tilde{P}_2)$ because the parameters of the model are assumed to be such that the merchant's supply of storage schedule intersects with the downward sloping demand schedule for long futures by risk averse institutional speculators rather than with the horizontal demand schedule of professional speculators.[6] The slope of the speculator's demand schedule, $\gamma_1 = 4/[(\alpha_H - \alpha_L)^2 \lambda]$, reveals that a higher level of risk aversion, as measured by λ, increases the speculator's demand for long futures. Result 2 asserts that such a shift results in higher price volatility.

Result 2 emerges because institutional speculators are willing to pay a premium price to hold long futures. The price premium, $f - E(\tilde{P}_2)$, is larger the more risk averse the institutional speculator because holding long futures reduces the variability in portfolio returns. The premium price induces merchants to increase storage relative to the level that would be chosen if speculation was exclusively professional. The additional stocks generate higher levels of price instability because period 1 prices are driven up to an inefficiently high level and period 2 prices in a low demand state are driven down to an inefficiently low level. Speculation may still be price stabilizing as a whole because the period 1 information outcomes are efficiently pro-

[6]The intercept of the demand schedule is $\gamma_0 = 4[\hat{\epsilon}^2 + \omega/(\alpha_H - \alpha_L)]$, so a sufficiently large value for the parameter ω ensures such an outcome.

vided, but the extent to which speculation stabilizes commodity prices is less with institutional speculators than with professional speculators.

Result 3. *In scenario B if the level of risk aversion of institutional speculators is sufficiently high then price volatility can be higher with versus without speculation.*

Result 3 is important because it shows that it is theoretically possible for speculation to result in higher rather than lower price volatility. With very high degrees of risk aversion speculators hold commodity futures strictly to minimize portfolio risk. As a result their demand for long futures is largely unresponsive to changes in period 1 information flows about period 2 commodity demand. Moreover, their inelastic demand for long futures results in a comparatively large positive value for $f - E(\tilde{P}_2)$. This large price wedge creates a sizeable distortion in the storage decisions of merchants, which in turn causes excessively high levels of price volatility.

Although it is theoretically possible that a high degree of risk aversion by institutional investors can raise price volatility above that which would occur with no speculation, such an outcome is unlikely to be observed in real world markets. A more reasonable conclusion is that speculation in general results in a first order decrease in price volatility, but some of this decrease will be offset with a second order increase in price volatility that can be attributed to the pricing distortions caused by institutional speculators. The net reduction in price volatility may be small or large, depending on the strength of the institutional speculation and the willingness of this group to bid f above $E(\tilde{P}_2)$. The outcome where a first order decrease in price volatility is partially offset by a second order increase in price volatility is consistent with data from the U.S. rice market, which is presented next.

3.1 Empirical Analysis

The U.S. rice market is not a major market like corn, wheat or soybeans, but nevertheless, as discussed above, there are two reasons why this market is well suited to examine the linkage between institutional speculation and price volatility. First, volatility in the world price of rice cannot be attributed to institutional speculators because there is no major futures market for rice outside of the United States. This feature, together with the fact that the U.S. rice market is small relative to the global market, implies the world price of rice can serve as an effective control variable for external sources of volatility that may impact the U.S. market. Second, futures contracts for rice started trading on the CBOT in 1994. Consequently, the U.S. cash market for rice can be divided into a pre-speculation (1982 - 1994) period and post-speculation (1995 - 2010) period. This division allows for a straightforward use of a dummy variable in the regression equation to measure the impact of speculation on price volatility. Figure 1 shows the U.S. cash price of rough rice from 1982 to 2010. Notice that prior to the price surge which began in 2002, the U.S. price of rice was relatively stable around a long term average price of about $150/tonne.

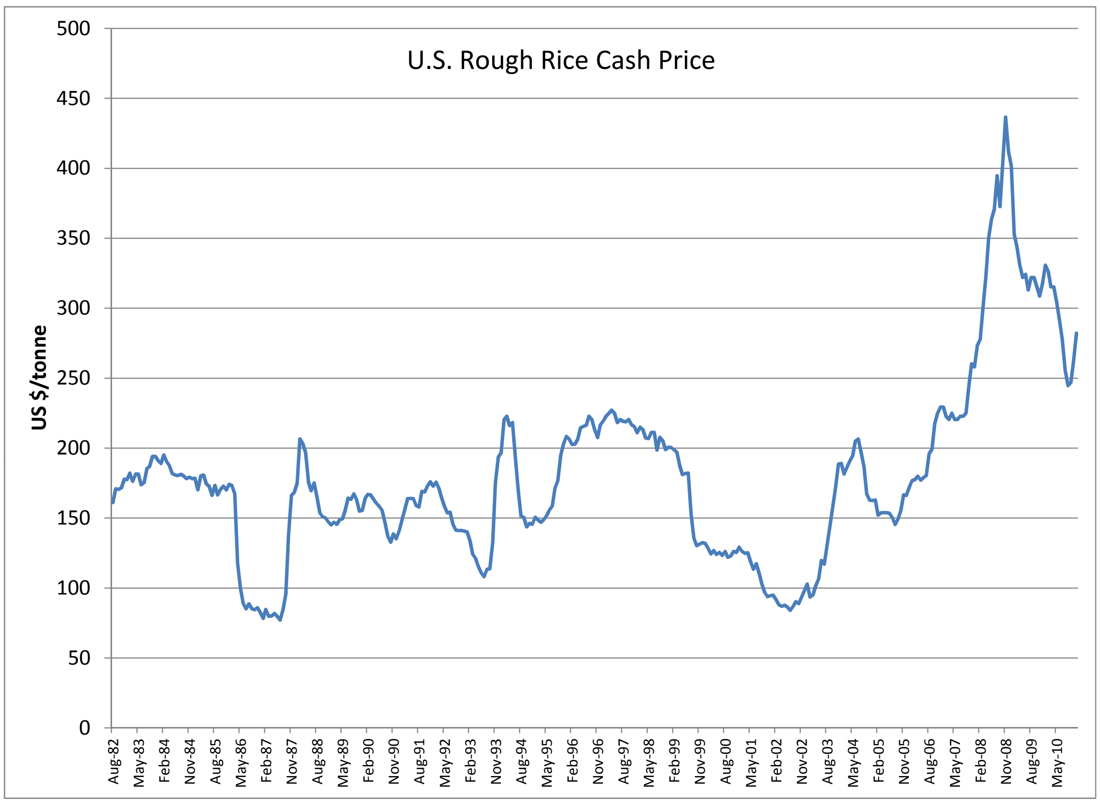

Figure 1: U.S. Cash Price of Rough Rice: 1982 - 2010

Figure 2 shows the U.S. cash price of rough rice and U.S. non-commercial open interest for (long) rice futures since the inception of futures trading in 1994.[7] Notice that the cash price

[7]A non-commercial trader is formally defined as someone who does not use the rice futures market to hedge, and therefore includes both professional and institutional speculators.

climbed from about $100/tonne in 2002 to nearly $450/tonne in late 2008. Over this same time period the open interest climbed from about 500 contracts to nearly 8000 contracts. This strong positive relationship between price and non-commercial open interest is similar to what was observed in other major U.S. commodity markets. Figure 1 makes it easy to understand why [Masters and White, 2008] and others who point out the strong relationship between price and non-commercial open interest and who argue that institutional speculation was the main cause of the 2002-2008 price surge have been effective in shaping public opinion.

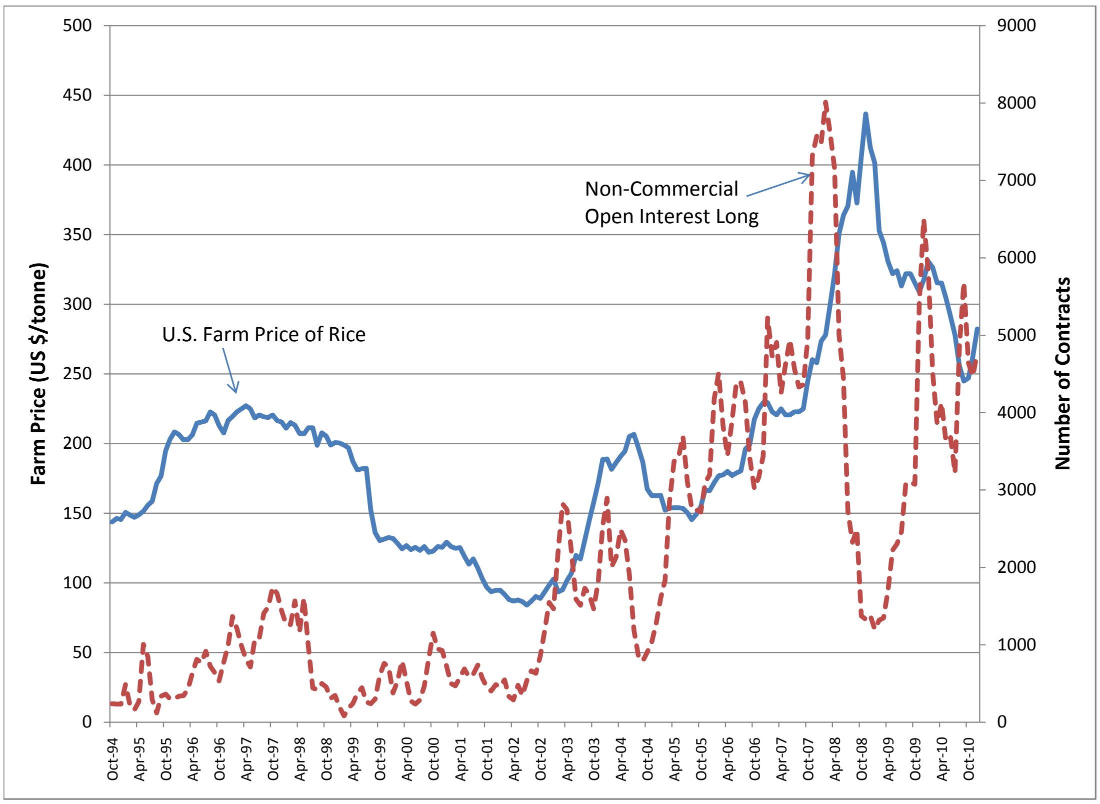

Figure 2: Non-commercial (speculative) positions in the U.S. rice futures market (2000-2010). Data from US Commodity Futures Trading Commission

A brief discussion of the U.S. rice market is useful before proceeding with the formal analysis. The U.S. has been exporting rice since the 1700s. In the early 1800s the U.S. was exporting more than 90 percent of its rice output, which amounted to about 10 percent of the total trade [Coclanis, 1993]. Currently only 2 percent of the annual world rice production belongs to the U.S, yet its share of trade in the global market continues to exceed 10 percent [Childs and Balwin, 2009]. Nearly all the rice in the United States is grown in five states: California, Louisiana, Arkansas, Mississippi, and Texas. California produces the short grain high quality japonica type, and the other four states produce the indica type because of their hotter climates [USDA, 2007]. Rough rice futures contracts began trading on the Chicago Board of Trade in 1994. Each futures contract obliges the owner to purchase or sell approximately 91 tons (or 2000 hundredweights) of long grain no. 2 rough rice with a milling yield of not less than 65 percent [CME, 2011]. The U.S. rice futures market is illiquid relative to other major U.S. crops such as corn and wheat. For instance, during the last trading week of 2009, the wheat futures market had 18 times and 117 times more non-commercial long and short open interest positions respectively than the rough rice futures market [CFTC, 2009].

3.2 Empirical Model

A common way to measure price volatility in a commodity market is to estimate a generalized autoregressive condition heteroskedasticity (GARCH) model [Antoniou and Holmes, 1995]. A GARCH model accounts for the impact of previous shocks and previous volatility on current period volatility. The generic GARCH(1,1) model is $\sigma_t^2 = a\epsilon_{t-1}^2 + b\sigma_{t-1}^2$ where $\epsilon_t = \sigma_t Z_t$. Within this set of equations ϵ_t is price expressed as a log return, Z_t is an independent and identically distributed standardized Gaussian random variable and σ^2 is a measure of price variance.[8] As well, the parameter "a" refers to the state memory factor and the parameter "b" refers to the variance memory factor. The system is referred to as GARCH(1,1) because within $\sigma_t^2 = a\epsilon_{t-1}^2 + b\sigma_{t-1}^2$ the explanatory variables include a single lag for h_t and a single lag for σ_t^2.[9] A relatively small (large) value for b implies a small (large) contribution from last period's variance to the magnitude of current period's variance. In the extreme case of $a = 0$ and $b = 1$ the variance is constant over time and the system reverts to discrete white noise.

For the current analysis the simple GARCH(1,1) model is modified by including the log return on the world price of rice, WP_t, and the log return on a broad commodity index, CRB_t,

[8]The log return, which is often referred to as a log difference, $log(P_t) - log(P_{t-1})$, is approximately equal to the percent change in price, $(P_t - P_{t-1})/P_{t-1}$.

[9]In the general class of GARCH(p,q) models the GARCH(1,1) is most commonly used.

in order to focus on price volatility in the U.S. market. In other words, WP_t and CRB_t are added to control for events outside of the U.S. that will affect the volatility of the U.S. price but which are not impacted by the actions of speculators trading in the U.S. market. The equation for r_t, which is the log return of the monthly average U.S. cash price for rough rice, can now be written as

$$r_t = \beta_0 + \beta_1 CRB_t + \beta_2 WP_t + \varepsilon_t \tag{13}$$

Let h_t denote the variance of ε_t in equation (13). The equation which describes how h_t evolves over time can be expressed as

$$h_t = \alpha_0 + \alpha_1 \varepsilon_{t-1}^2 + \alpha_2 h_{t-1}^2 + \alpha_3 D_t + \alpha_4 P_t \tag{14}$$

The dummy variable which allows the variance of ε_t to jump up or down with the start of futures trading in October, 1994 is denoted D_t. Antoniou and Holmes [1995] used a similar dummy variable procedure. The last explanatory variable in equation (14) is P_t, which is the prevailing cash price level for rough rice. This variable has been included because Reilly and Drzycimski [1978] and others have shown that commodity prices tend to be more volatile at lower levels.

Table 3 provides summary statistics for the main variables in the GARCH(1,1) regression.[10] For each variable the three rows show the summary statistics for the full sample period, the pre-futures sample period and the post-futures sample period, respectively. The last two columns show that the spread between the minimum and maximum values of r_t is significantly lower in the post-market period than in the pre-market period. The fourth column shows that the standard deviation of r_t is significantly lower in the post-market period than in pre-market period, even though the standard deviation for the log return on the world price, WP_t, is practically the same for the two time periods. These results serve as preliminary evidence that the introduction of futures trading in the U.S. rice market has lowered U.S. price volatility.

[10]Data for the rough and world price of rice were obtained from the 2010 United States Department of Agriculture (USDA) Rice Yearbook.

Variable	Obs	Mean	Std Dev	Min	Max
r_t (1982 - 2010)	342	0.00187	0.05639	-0.35667	0.36471
r_t (1982 - 1994)	145	-0.00048	0.06991	-0.35667	0.36471
r_t (1995 - 2010)	197	0.00361	0.04397	-0.17846	0.11502
CRB_t (1982 - 2010)	342	0.00256	0.02691	-0.14509	0.07621
CRB_t (1982 - 1994)	145	0.00091	0.01937	-0.04719	0.07585
CRB_t (1995 - 2010)	197	0.00378	0.03131	-0.14509	0.07621
WP_t (1982 - 2010)	342	0.00192	0.06374	-0.28127	0.41164
WP_t (1982 - 1994)	145	-0.00069	0.06408	-0.28127	0.22857
WP_t (1995 - 2010)	197	0.00385	0.06358	-0.19008	0.41164

Table 3: Summary Statistics for Regression Variables

3.3 Empirical Results

The STATA estimates of the GARCH(1,1) model, which is given by equations (13) and (14), are presented in Table 4. The commodity index variable, CRB_t, is not statistically significant in the first regression (left column), and so it is excluded from the second regression (right column). Notice that the estimated coefficients change very little when the CRB_t variable is dropped. The coefficient on WP_t is positive and significant, which is an expected result. The estimated coefficients for the state memory variable, ε_t^2, and the variance memory variable, h_t^2, take on intermediate fractional values, which are typical for a GARCH(1,1) model. Intermediate values ensure stable long run volatility outcomes. The negative coefficient for P_t in equation (14) is consistent with the findings of Reilly and Drzycimski [1978] who discovered higher levels of price volatility at lower commodity price levels.

Most importantly, Table 4 shows that the coefficient on the time dummy, D_t, is negative and statistically significant at the 99 percent level. This result implies that the cash price volatility in the U.S. rice market decreased by a significant amount after the introduction of the CBOT rice futures contract in 1994. It is important to keep in mind that this reduction in price volatility was measured while controlling for changes in volatility in the world price of rice. In other words, the negative value of the dummy variable does not imply a lower overall level of price volatility after the introduction of futures trading, but rather a less volatile U.S. price relative to the world price. The result that price volatility in the U.S. rice market is lower after the 1994 introduction of futures trading despite the surge in non-commercial open interest during the 2002 - 2007 period is the main result of this empirical analysis.

There are two shortcomings of this empirical analysis. First, futures trading is being used as a proxy for speculation, and second the implicit assumption is that the mix of professional and institutional speculation is constant over the post 1994 sample period. The first shortcoming is unlikely to be important because speculation is the most obvious way in which futures trading can cause a change in price volatility. The second shortcoming is somewhat more problematic because as Figure 2 shows professional speculation was dominant during the 1994 - 2001 period and institutional speculation was dominant during the 2002 - 2007 period. The second shortcoming could be addressed by enriching the empirical model in a way that reflects the gradual growth in non-commercial speculation. A second approach would be to examine the estimated volatility plot from the current model in order to determine whether price volatility grows with the growing importance of non-commercial speculation. This second approach is implemented below.

Figure 3 shows the GARCH(1,1) fitted values for the price volatility variable, h_t. The average level of variability is 0.003344 for the entire period, 0.004864 for the period before the introduction of the futures market and 0.002213 for the period after the introduction. Figure 3 reveals that the significant reduction in price volatility that emerged from the regression results can largely be attributed to the presence of large volatility spikes in September of 1986, January of 1988 and January of 1994, and the corresponding absence of such spikes after the introduction of the futures trading. It is therefore reasonable to interpret the elimination of these volatility spikes as the first order beneficial effects of speculation on price volatility.

Given that the regression results and volatility plot in Figure 3 both point to a first order reduction in price volatility that can be attributed to speculation, the next question is whether there is a corresponding second order increase in volatility that can be specifically linked to trading by institutional speculators. Close inspection of the right hand side of Figure 3 shows

	Dependent Variable, r_t	
Constant	0.0089 (0.030)	-0.0007 (0.00292)
CRB	0.0352 (0.0749)	
WP	0.0890 (0.0259***)	0.0903 (0.0257***)
	Dependent Variable, h_t	
Constant	-5.8528 (0.3188***)	-5.914 (0.2963***)
ε_{t-1}^2	0.4226 (0.0861***)	0.4294 (0.0866***)
h_{t-1}	0.3277 (0.0849***)	0.3194 (0.0834***)
D_t	-0.5124 (0.1381***)	-0.5039 (0.1373***)
P_t	-0.0050 (0.0025**)	-0.0046 (0.0024*)

Standard errors are in parentheses.

* (90%), ** (95%) and *** (99%) significance.

Table 4: Parameter Estimates for GARCH(1,1) Model

that indeed high frequency, low magnitude price volatility appears to be present throughout 2002 - 2008, which is the time period corresponding to the surge in non-commercial open interest. Although this method does not formally establish causality, the result that second order volatility appeared when institutional speculation surged nevertheless supports the conjecture that institutional speculation introduces second order pricing distortions that can offset some of the first order beneficial impacts of speculation.

Given this focus on first and second order volatility effects, it is of interest to re-estimate the GARCH model while controlling for the large volatility spikes in 1986, 1988 and 1994. This procedure is useful because it isolates the second order volatility effects and allows the statistical significance of these effects to be formally tested. Table 5 shows the coefficients for the re-estimated GARCH(1,1) model, which includes a new dummy variable, $\hat{D}_t$, for September of 1986, January of 1988 and January of 1994. Most of the coefficients in Table 5 are similar in sign and magnitude to the coefficients of the original model (Table 4). The main exception is that the sign of the original dummy variable, D_t, has switched from significant negative to

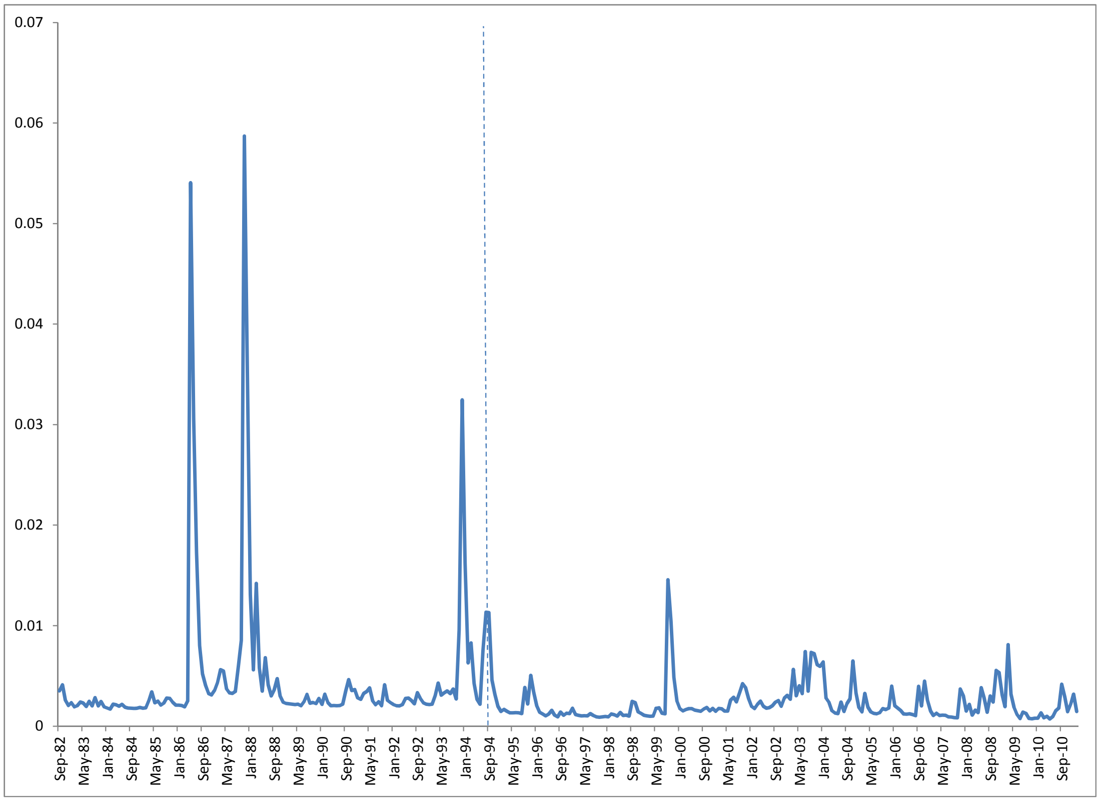

Figure 3: Estimated GARCH(1,1) variability with full data sample.

significant positive. In other words, as hypothesized the second order volatility effects which appear along with the surge in non-commercial speculation are significant.

4 Conclusions

Volatile agricultural commodity prices have resulted in an on-going debate about the causes and policy solutions for this socially undesirable outcome. One particularly contentious issue concerns the link between commodity price volatility and investment in commodity futures by large scale institutional speculators such as index and hedge funds. The fact that billions of dollars poured into these funds at the same time that commodity prices surged is often cited as strong evidence that institutional speculation is an important contributor toward excess price volatility and should therefore be regulated. Others have argued that the simultaneous surge in

	Dependent Variable, r_t	
Constant	-0.0005 (0.0022)	-0.0005 (0.0022)
CRB	0.0711 (0.0838)	
WP	0.1330 (0.0502**)	0.1368 (0.0481**)
	Dependent Variable, h_t	
Constant	-8.402 (0.3992***)	-8.401 (0.3989***)
ε_{t-1}^2	0.4165 (0.1157***)	0.4126 (0.1173***)
h_{t-1}	0.1764 (0.0711**)	0.1797 (0.0715**)
D_t	0.7575 (0.2255***)	0.7536 (0.2224***)
P_t	0.0022 (0.0016)	0.0022 (0.0016)
$\hat{D}_t$	2.9757 (0.2733***)	2.9709 (0.2725***)

Standard errors are in parentheses.

* (90%), ** (95%) and *** (99%) significance.

Table 5: Revised GARCH(1,1) Estimates While Controlling for First Order Volatility Spikes

speculation and commodity prices implies association and not necessarily causation. Moreover, the theoretical arguments which link speculation with commodity price volatility are weak.

An important issue in this debate centers on the assumptions made about the investing behaviour of institutional investors. In one scenario speculators are "amateurs", invest with a "herd" mentality or use fixed investment rules such as continually rolling over long futures. With this assumption it would not be difficult to build a model which establishes a strong link between speculation and commodity price volatility. In a second scenario fully informed and rational investors hold commodity futures to diversity their personal portfolios. This scenario is certainly realistic because it is widely known that during the 2002 - 2007 commodity price surge various types of commodity index funds were aggressively marketed as a unique asset class which provides diversification benefits and upside potential for ordinary investors. Reality likely lies somewhere between these two scenarios. Sorting out the extent that reality is closer to one particular scenario is in the domain of empirical analysis.

This current analysis is squarely aligned with scenario B. Its specific purpose was to demonstrate that fully informed and rational speculation has two distinct impacts on commodity price volatility. The main impact is a first order reduction in price volatility that results from a more efficient allocation of resources. Specifically, speculation allows for a more targeted price forecast, and merchants will adjust the amount stored in accordance with the price forecast. The secondary impact is a pricing distortion which arises from the excess demand for long futures by institutional investors and which offsets some of the first order reduction in price volatility. Result 2 showed that the level of offset will increase as the demand for futures by institutional investors increases. Result 3 established that it is theoretically possible for speculation to raise rather than lower price volatility if the demand for futures contracts by institutional investors is sufficiently large. Result 3 is not likely to describe real world markets. The preferred interpretation is the first order decrease and second order increase in volatility story, which was discussed above.

The U.S. rice market lends itself to empirical analysis because it is possible to effectively isolate volatility in the U.S. market from volatility in world markets both before and after the introduction of a futures contract for rice in 1994. The graph of the fitted GARCH volatility outcomes clearly shows that a series of large volatility spikes which were present before 1994 are no longer present after 1994. Moreover, during the 2002 - 2007 period, which is when investment by non-commercial speculations and the price of rice both surged, the GARCH graph reveals an on-going series of high frequency, low magnitude price volatility, which was not present prior to 1994. Both of these results are consistent with the theoretical arguments that speculation which involves large scale institutional investment can have first and second order impacts on commodity price volatility.

The theoretical and empirical modeling used in this paper is based on a number of strong assumptions. There is certainly scope for relaxing some of these assumptions and making the results more general. There is also scope for undertaking a similar type of empirical analysis for other agricultural commodities to determine if the first order - second order volatility results that appear to characterize the U.S rice market are also present for other agricultural commodities.

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A Proofs of Formal Results

A.1 Result 1

To establish the sign of equation (12) it is first necessary to make the parameters of this equation more explicit. Begin by substituting in equation (9) with $\hat{\epsilon} = \epsilon$ for S^{Bear}, $\hat{\epsilon} = -\epsilon$ for S^{Bull} and $\hat{\epsilon} = 0$ for S^{No}. After the substitution equation (12) can be rewritten as

$$\Delta = 2\left[M^2 - N(\alpha_H - \alpha_L)^2\epsilon^2\right] \tag{A.1}$$

where

$$M = \frac{\phi_0 + \phi_1 Z}{1 + 2\phi_1} - \frac{\phi_1\gamma_0 + \gamma_1(\phi_0 + \phi_1 Z)}{(1 + 2\phi_1)\gamma_1 + \phi_1} \tag{A.2}$$

and

$$N = \frac{\gamma_1\phi_1[1 + \phi_1(1 + \gamma_1)]}{[(1 + 2\phi_1)\gamma_1 + \phi_1]^2} \tag{A.3}$$

Recall from the discussion below equation (9) that scenario A in Result 1 can be simulated by setting $\lambda \to 0$, which in turn implies $\gamma_1 \to \infty$. To examine the sign of equation (A.1) with $\gamma_1 \to \infty$ it is necessary to use l'Hôpital's rule to evaluate the sign of M and N in equations (A.2) and (A.3), respectively. The desired expression can be written as

$$\lim_{\gamma_1 \to \infty} \Delta = -2\left(\frac{\phi_1\epsilon(\alpha_H - \alpha_L)}{1 + 2\phi_1}\right)^2 \tag{A.4}$$

The negative sign of equation (A.4) implies that price volatility is lower with versus without speculation.

A.2 Result 2

An increase in λ decreases γ_1 because $\gamma_1 = 4/[(\alpha_H - \alpha_L)^2\lambda]$. Result 2 can therefore be established by showing that equation (12) is a decreasing function of γ_1. This latter outcome holds if the variable M given by equation (A.2) is a decreasing function of γ_1, and the variable N given by equation (A.3) is an increasing function of γ_1. The latter result follows immediately because in the proof of Result 1 it was established that N takes on a negative value in the limit as $\gamma_1 \to \infty$, and from equation (A.3) it can be seen that $N = 0$ when $\gamma_1 = 0$. To establish that M is a decreasing function of γ_1 differentiate equation (A.2) with respect to γ_1 to obtain

$$\frac{dM}{d\gamma_1} = -\frac{(1+2\phi_1)\phi_1}{[(1+2\phi_1)\gamma_1 + \phi_1]^2}\left(\frac{\phi_0 + \phi_1 Z}{1+2\phi_1} - \gamma_0\right) \tag{A.5}$$

Recognize that within equation (A.5), the expression $(\phi_0+\phi_1 Z)/(1+2\phi_1)$ is equivalent to S^{No}. Hence, equation (A.5) takes on the required negative sign if it can be shown that $S^{No} > \gamma_0$. This restriction holds because from the speculators demand schedule, $X^* = \gamma_0 - \gamma_1[f - E(\tilde{P}_2)]$, it can be seen that $\gamma_0 < X$ for $f > E(\tilde{P}_2)$. Since, $S^{No} \approx X^*$ it follows that $S^{No} > \gamma_0$.

A.3 Result 3

The goal is to show that Δ given by equation (12) takes on a positive value for $\gamma_1 = 0$, which arises when $\lambda \to \infty$ (i.e., the speculator is infinitely risk averse). Noting from Result 1 that $\Delta < 0$ with $\gamma_1 \to \infty$, if it can be shown that $\Delta > 0$ with $\gamma_1 = 0$ then it must be the case that for a sufficiently high level of risk aversion price volatility is higher with versus without speculation. Using equation (A.2) note that

$$\lim_{\gamma_1 \to 0} M = \frac{\phi_0 + \phi_1 Z}{1+2\phi_1} - \gamma_0 \tag{A.6}$$

Using the results from the proof of Result 2 together with equation (A.6) it follows that M takes on a positive value. Using equation (A.3) note that N vanishes for $\gamma_1 = 0$. With a positive value for M and a zero value for N it follows immediately from equation (12) that Δ takes on a positive value when $\gamma_1 = 0$.