Essays on agricultural commodity spot and forward markets

Essays on Agricultural Commodity Spot and Forward Markets

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Abstract

This thesis explores several topics related to agricultural commodities. It is comprised of three empirical chapters:

In Chapter 2, we show the validity of investing capital in fertilizer mining companies, both from a market return perspective for individual or institutional investors, and from a hedging standpoint for insurance companies and other economic actors exposed to inflation risk and high agricultural commodity prices. First, we explore the relationship between corn, wheat, and fertilizers, showing how price spikes in corn and wheat, followed by a price spike in fertilizers, made fertilizers visible to investors for the first time. We then analyse an exhaustive sample of listed fertilizer-mining companies and look at the sensitivities of their stocks to agricultural indexes and the fertilizer index in order to better explain the high returns they offered at the time of the first food crisis.

Chapter 3 focuses on corn and wheat and is twofold. Firstly, we argue that the coefficient of variation and standard deviation of prices are more informative measures of uncertainty than the volatility of returns, since it is food prices and their "volatility" that matter for the survival of human beings. Secondly, we compare the quality of future price prediction provided by individual forward contracts with the geometric average of the forward curve introduced by Borovkova and Geman (2006). We find that the average value of the forward curve, $\bar{F}$, provides several advantages over the use of forward prices of individual maturities. Due to its construction as an average of expectations, it is a better predictor of future changes in spot prices when compared with individual maturities.

In Chapter 4, we turn our attention to live cattle markets and concentrate our study on the relationship between the two largest live cattle markets in the world, US and Brazil. First, we analyse the relationship between these two markets, which has never been addressed in the financial literature. We then identify several forward curve based strategies using Future contracts from the two main cattle exchanges in the US and Brazil. For this purpose, we introduce two measures of distance between forward curves. Using a measure of distance and the property of integration between these two markets in the period 2007-2013, we devise a profitable pairs trading strategy.

Declaration and Acknowledgements

Chapter 2 is based on the article "Investing in fertilizer–mining companies in times of food scarcity" co-authored with Professor Hélyette Geman and published in 2013 in *Resources Policy*, *38*(4), 470-480. Chapter 3 is based on the article "Revisiting uncertainty and price forecast indicators in corn and wheat markets" co-authored with Professor Hélyette Geman and published in 2015 in the *Journal of Agricultural Extension and Rural Development*. Chapter 4 is based on the article "Live cattle as a new frontier in commodity markets" co-authored with Professor Hélyette Geman and published in 2015 in the *Journal of Agriculture and Sustainability*.

I would like to thank my supervisor, Hélyette Geman for her invaluable support and guidance. I would like to thank the School of Business, Economics and Informatics and the Department of Economics, Mathematics and Statistics at Birkbeck College, University of London, for funding my PhD and their continuous support during my studies.

Pedro Vergel Eleuterio

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Chapter 1. Introduction

1. Motivation

Traditionally, commodities are classified into three main groups, or subclasses: metals, agriculturals, and energy. Agricultural commodities are further categorized into softs, grains, and livestock. Fertilizers can be considered as a separate category. They are strongly connected to agricultural commodities since they play an essential role in their production, but they are also connected to other commodities since their production involves huge amounts of energy, usually natural gas, and water, making them similar to minerals.

Agricultural commodities are of vital importance on a global scale. The price dynamics of agricultural commodities are driven mainly by supply, demand and inventories. In the agricultural year 2006-2007, several weather events around the world sent corn and wheat prices to unprecedented levels (see Figure 1.1). As of that moment, food price risk became a large concern for government and regulators alike. Food security, followed by energy security, is the main objective of most countries. In the US, India, China, and the EU, an enormous amount of effort and resources are devoted to policies concerning food, agricultural commodities, and fertilizers. There are two particular situations that make the issue of food security an increasingly pressing matter: a constrained supply of land and a general increase in the demand for food worldwide.

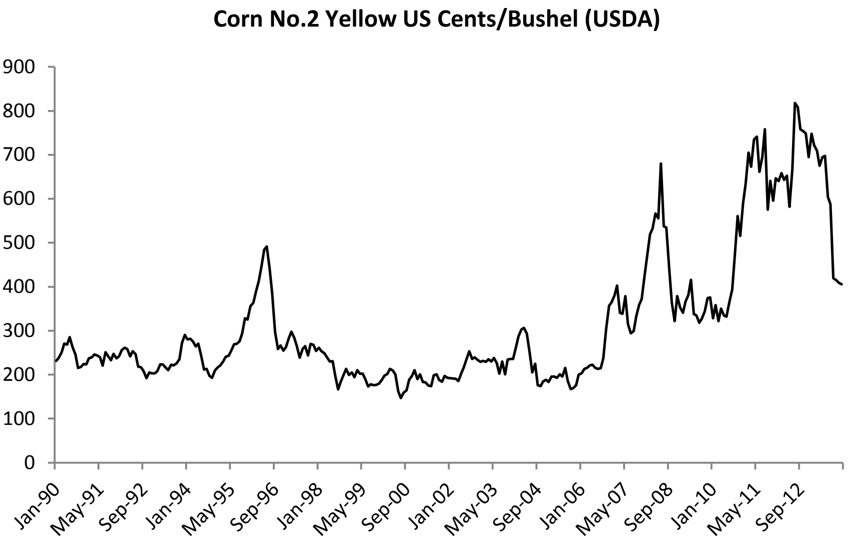

Figure 1.1. Corn prices from 1990 to 2013

There are three classes of commodities that are of vital importance to food security on a global scale: fertilizers, which are becoming an asset class in its own right; grains, particularly corn and wheat; and cattle. All three commodities are closely linked. Fertilizers are vital for the successful growth and increased yields of corn and wheat. In turn, corn and wheat are essential for the nutrition of cattle and, therefore, also crucial in meeting the objectives for meat production. It is the changing price dynamics of these key commodities coupled with the issue of global food security that provides the motivation for our thesis and prompt several important research questions that have not yet been addressed in the literature. In particular, we ask what tools and trading strategies can be made available to a broad range of market participants – including farmers, policy makers, and investors – which successfully address the most recent changes in the agricultural commodity arena.

2. Structure of the Thesis

The following three chapters address issues of food security and food price risk from a financial standpoint. We develop the subject from two different viewpoints that are intrinsically related. In no particular order, one viewpoint is that of developing tools that can be used for governments and regulators in these markets to address food security, such as using different measures of dispersion and information embedded in the forward curves as signals for different policies. Another is the viewpoint of commercial players and investors (such as pension funds, insurance companies and farmers who need to hedge against high agricultural commodity prices), in terms of developing innovative investment and hedging strategies, for example, by using commodity related company stocks or the information embedded in Futures contracts

In order to increase food security, all participants need to be aware of the information available to them, from both the financial derivatives themselves as well as the fundamentals of the physical agricultural commodity markets in question. For this reason, a discussion of the physical markets of relevant commodities are included in each chapter.

We use Futures prices to conduct our investigations, including for the purposes of implementing new measures for predicting future spot prices and devising original investment strategies. Although every agricultural commodity is traded on the spot market, historical data from Futures markets, characterized by liquidity, transparency, and standardization of the physical good, is typically used to study the price trajectories of commodities. Since buying the physical good can be costly and problematic, investors such as hedge funds use Futures contracts as a substitute for the spot market, with the added benefit of being able to take both short and long positions. It is well known and documented that spot prices and Futures prices are strongly connected, hence the existence of the spot forward relationship. We use Futures prices for corn, wheat, (Chapters 2 and 3) and live cattle (Chapter 4) to explore various relationships between commodities, implementing new measures for predicting future spot prices, and developing original investment strategies.

Worldwide, there are a number of important Exchanges where corn, wheat, and a wide variety of other agricultural commodities are traded. In Chapters 2 and 3, we use corn and wheat Futures from the Chicago Board of Trade (CBOT), the most important commodities Exchange in the United States, founded in 1848. In July 2007, the CBOT and the Chicago Mercantile Exchange (CME) merged to form the CME Group and, in August 2008, the New York Mercantile Exchange (NYMEX) and the Commodity Exchange (COMEX) joined the CME Group. These four markets operate as contract markets of the CME Group. In Brazil, the Brazilian Mercantile and Futures Exchange merged with Bovespa (Bolsa de Valores de Sao Paulo) in May 2008, creating the second largest stock exchange in the world, BM&F Bovespa. Currently, BM&F Bovespa is fully electronic and trades a wide number of agricultural commodities. It also has extensive agreements with the CME. In Chapter 4, we use BM&F Bovespa live cattle Futures.

From the mid-2000s, there has been a huge increase in the popularity of investing in commodities and their inclusion in investment portfolios as a diversification tool. Among other ways, we can gain long exposure to commodities by purchasing the physical asset, stocks of commodity related companies, commodity indexes, and Future contracts. We address investment in corn, wheat, fertilizers and live cattle in Chapters 2, 3, and 4. We also introduce several new investment strategies based on the trading of Futures contracts, thus making several important contributions to the literature.

2.1. Contributions

. The goal of Chapter 2 is twofold. The first is to shed some light on fertilizers, a commodity totally forgotten by the financial literature. In particular, we show that the disruptive spike in corn and wheat markets in 2006 was followed by a spike in fertilizer prices in 2007, which made fertilizers visible to investors. Secondly, we exhibit, through an analysis of listed fertilizer-producing companies over the period 2004 to 2012, that investing in these companies would have produced high “alphas” over the security market line, in particular over the period January 2004 to December 2007. This property is in alignment with the “leverage” exposure to commodities produced by commodity mining equities. It is commonly acknowledged that there exists a leverage effect, such as in the case of gold investing, as presented in a major paper by Tufano (1998) and others (see Brimelow, 1996; Blose and Shieh, 1995; McDonald and Solnik, 1977). We extend this approach to the case of fertilizer companies.

In the first part of Chapter 3, we study alternative measures of uncertainty for corn and wheat. In a report to the EU Commission, Geman and Ott (2013) argued that the usual volatility, defined as the standard deviation of returns traditionally used in portfolio theory, option pricing, and finance in general, is not necessarily a good measure of uncertainty in the case of commodities. This especially applies to *agricultural commodities*, in which case absolute prices matter for populations, and hence also for governments and regulators. We investigate this point by considering two alternative measures of uncertainty, namely the coefficient of variation (CV) and the standard deviation of prices, and show that the CV and standard deviation of prices would have provided better warning signals with regards to rising food prices, and the related crises since 2006 in countries such as Tunisia and Egypt.

We turn our attention to spot price predictors for wheat and corn markets in the second part of Chapter 3, and find that the predictive power of individual maturities is greatly reduced in times of planting, heading, and harvesting for corn and wheat in the Rational Expectations Hypothesis (REH) framework. When we study the “theoretical optimal lags” of prediction we find that corn and wheat differ, since corn Future nearby contracts predict at earlier lags than those of wheat. Finally, we show that the average value of all liquid forward contracts, introduced in Borovkova and Geman (2006), captures this property and provides several advantages over the use of forward prices of individual maturities.

In Chapter 4, we address the relationship between the US and Brazilian live cattle markets, the two largest cattle markets in the world. Like fertilizers, cattle has essentially been unstudied in the literature. The goal of this Chapter is twofold: 1) to describe the main properties of cattle markets around the world and 2) identify trading strategies based on the forward curves associated with the two main cattle exchanges, the CME in the US and the BM&F Bovespa in Brazil. With respect to the latter goal of this Chapter, we introduce two measures of distance between forward curves, which allow us to take into consideration the information contained in the entirety of the forward curves for live cattle. We also devise a profitable strategy related to trading pairs of Futures contracts for Brazilian and U.S. live cattle markets and compare it to strategies from existing literature (Bianchi et al., 2009; Gatev et al., 2006).

Lastly, in Chapter 5, we present our final remarks, a summary of the main findings for Chapters 2, 3 and 4, and suggestions for further research.

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Chapter 2. Performance of publicly traded fertilizer-mining companies and their relationship to agricultural commodities and fertilizers.

1. Introduction

In a world projected to see a dramatic increase in the demand for food, fertilizers are gaining the status of a commodity in their own right. The quantity of land essentially remains unchanged while the world population is increasing and people living in developed emerging countries such as China consume more proteins, in turn using vast amounts of grains (seven kilograms of feed grains for one kilo of beef, four kilos for one of pork, two in the case of poultry). In fact, according to a recent report from the Food and Agriculture Organization (FAO), the amount of arable land per human being should decrease to 0.20 in 2020, a decline from 0.45 hectares in 1960. Along the same lines, a very ominous paper by Hertel (2011) views a “perfect storm in the making” regarding the issue of adequate supply of agricultural land at the horizon 2050 and concludes on the likely occurrence of a number of ‘regional’ storms. Furthermore, land erosion is happening in various regions, particularly in Africa. One of the few solutions to feed the planet, which has the merit of being global as well as local, is to increase *yields* in already cultivated land. This, in turn, makes fertilizers a central element of the agricultural commodities picture. According to Stewart et al. (2005), fertilizers accounted for 60% of the registered yield increases in the last five years.

China and India have been importing increasing quantities of fertilizers to meet their rising food demand. Like the whole mining sector, fertilizers are strongly linked to energy markets as they require vast amounts of energy in the extraction, processing and shipping phases. Nitrogen, for instance, is available in large volumes in the atmosphere, but its transformation into ammonia is highly demanding in terms of energy. Similar to all other storable commodities, fertilizers travel the world, going from producing countries to those needing the imports.

In most cases, the three types of fertilizer layers, namely potash, urea, and phosphate, are necessary as nutrients for the soil. The three are components of the World Fertilizer Index produced by the World Bank, the index on which we focus because of this feature and for its transparency. Also, a study of fertilizers cannot be done without the inclusion of corn and wheat, since these agricultural commodities require the greatest quantities of fertilizer compared with other crops.

The goal of this chapter is twofold. The first is to shed some light on fertilizers, a commodity that has never been addressed in the financial literature. Through structural break analysis, we show that the disruptive spike in corn and wheat markets in 2006 was followed by a spike in fertilizer prices in 2007, which made fertilizers visible to investors. Our second goal is, in the absence of Futures contracts and other liquid financial instruments, to investigate if investing in fertilizer-mining companies is a profitable investment and a good way to hedge against agricultural commodity prices, We exhibit, through an analysis of listed fertilizer-producing companies over the period 2004 to 2012, that investing in these companies would have produced high “alphas” over the security market line, in particular over period January 2004 to December 2007. This property is in alignment with the “leverage” exposure to commodities produced by commodity mining equities.

This chapter is organized as follows. Section 2 presents the fertilizer markets, as well as the behavior of corn, wheat and fertilizer index prices over the period 1991 to 2012. Section 3 describes the fertilizer companies in our sample and exhibits their performance over the two periods surrounding the financial crisis, namely January 2004 to December 2007 and January 2008 to December 2012. Finally, in Section 4, we conduct a regression of the share returns on fertilizer and agricultural commodity indexes. Section 5 concludes.

2. Some Fundamentals of Fertilizers and Agricultural Commodity Markets

In this section, we provide an overview of the physical aspects of fertilizers and related markets and indexes. Since the price of commodities is primarily dictated by supply, demand, and inventory, an understanding of their fundamentals is essential in order to successfully invest in the respective market. We then proceed to look at prices and perform a structural break analysis in order to explain the dramatic changes in the dynamics of fertilizer and how they relate to associated agricultural markets, namely corn and wheat.

According to the Fertilizer Institute, corn and wheat are the crops that use the most fertilizer, with a bushel of corn requiring approximately 1.5 to 2 pounds of fertilizer nutrients and a bushel of wheat needing about 2.5 to 3.5 pounds of fertilizer. These numbers vary depending upon the method of cropping. According to the USDA, more than 40 percent of all commercial fertilizer in the U.S. is used solely on corn (Chen, 2013). It is estimated that fertilizers account for 40 to 60 percent of food production worldwide. Given these statistics, and the dependence of fertilizer on the supply and demand of corn and wheat, their inclusion in our investigation is highly relevant.

2.1. Fertilizer markets

The use of commercial fertilizers has steadily increased in the last 50 years, rising almost twentyfold in the case of nitrogen to the current rate of 100 million tonnes per year. The consumption of phosphate has risen from 9 million tonnes per year in 1960 to 40 million tonnes in 2000. The production of potash today exceeds 30 million tonnes per year, mostly for use in fertilizers. According to the FAO, fertilizer consumption over the period 1993 to 2007 has increased at an annual rate of 2.6% for phosphate, 3.6% for potash and 2.4% for nitrogen. In dollar values, potash prices for instance went from $200 a tonne in 2004 to an expected level of $1500 by 2020. A maize crop yielding 6 to 9 tonnes of grains per hectare requires 31 to 50 kg of phosphate fertilizer, soybean requires 20 to 25 kg per hectare. The links of fertilizers with crucial commodities, their importance at a global level in feeding the world population and the fact that only a few countries and companies control their production have increased the relevance of research on the subject, which is fairly thin for the time being.

All three main categories of fertilizers - nitrogen (N), phosphate (P) and potash (K) - are, in general, nutrients which are necessary in improving land yield. Sulphur is sometimes added to help the soil absorb the nitrogen or increase the seed oil content of crops such as soybeans and flax; in this case, sulphur is used in a ratio of 1 to 20 with respect to nitrogen. Since our focus here is going to be around the crucial case of corn and wheat, and sulphur represents a very minor element in the picture, we will leave it outside the discussion of this paper.

Phosphate, the first key fertilizer, contains phosphorous, an important element for the human body to build and repair cell walls. It is found in the form of phosphate rock, which is processed into DAP (Di-Ammonium of Phosphate) by the separation of phosphate from the mix of sand, clay and phosphate. While nearly thirty countries produce phosphate rock, China, the US and Morocco are the largest producers, accounting together for two-thirds of the world production. Morocco alone accounts for more than 30% according to data from the US Geological Survey. Annual global production is around 170 million tonnes while estimated reserves stand at 15 billion tonnes; Morocco represents close to half of the world's proven phosphate rock reserves. The world's top producers also include Mosaic of the US, Fos Agro of Russia and Yuntianhua Group of China. It is important to emphasize that fertilizer firms need large amounts of power, oil and gas for their mining activities, as well as trucks, pipelines and shipping facilities for their distribution business, representing altogether vast amounts of operating capital. Israel and Jordan, which are both significant producers of phosphate, pump part of the necessary water from the Dead Sea. And in October 2012, the Hydrological Service of Israel observed that the salty lake had lost 1.5 meters of water depth between September 2011 and September 2012, the steepest decline in 60 years, because of evaporation, phosphate industry and crops' irrigation. This Service urged all fertilizer companies in the region to reduce the siphoning of water from the Dead Sea.

Potash, on the other hand, is the most common name for various mined salts that contain potassium in water-soluble form and has been used since antiquity as a soil fertilizer. Today, potash is produced worldwide in amounts exceeding 30 million tonnes per year. The largest known potash deposits are spread all over the world, from Canada to Brazil, Belarus, China, Germany, Israel, Jordan and the world's purest potash deposit in New Mexico, US. Canada is the world's largest producer, followed by Russia and Belarus. The most significant reserve of Canada' s potash is located in the province of Saskatchewan, and controlled by the Potash Corporation of Saskatchewan. The world's largest consumers of potash are China, the United States, Brazil and India. Brazil imports 90% of the potash it needs. Potash is important for agriculture because it improves water retention, nutrient value, taste, disease resistance of food crops and yield.

As established by Huang (2009), rises in fertilizer prices are primarily influenced by rising costs in the production of fertilizers (fuel prices and human labour in particular, like in all mining activities) and increased demand as farmers try to raise their output to benefit from agricultural commodity prices that rose three fold between 2001 and 2007. To analyze the evolution of fertilizer prices over the last decade, we have chosen to use the World Bank Fertilizer Index, depicted in Table 2.1, an index which contains the three types of fertilizers.

Table 2.1
The World Bank Fertilizer Index: components and weights

The World Bank Fertilizer Index (%)	
Natural Phosphate Rock	16.9
DAP	21.7
Potassium	20.1
Nitrogen	41.3

Phosphate appears twice in the index, both in the form of the extracted phosphate rock and also in the form of DAP (Di-Ammonium of Phosphate), reflecting the importance of this constituent and the fact that phosphate is traded both in its raw form (phosphate rock) as well as the transformed one (DAP). The units that transform the phosphate rock into DAP are quite expensive to build but allow countries, often emerging ones, to benefit from a vertical integration of the supply chain on their own territories. At the same time, the cost of shipping the phosphate rock from the place of extraction to very distant destinations around the world becomes obviously lower in the DAP form, where mud and dust around the phosphate have been eliminated. In an analogous manner, potassium is extracted in the form of mined salts and then transformed into nitrate and sulphate of potassium, which are the fertilizer forms.

The flows of fertilizers across the world are quite interesting. In general, potash travels from Canada into the US and China. It also goes from the Former Soviet Union into India. Phosphate rock and DAP go from Morocco and Tunisia into Europe and India, and from Syria into India. DAP goes from the US into India, nitrogen from China into India. This shows a large array of shipping activities, since no single country produces the three components. In order to feed its population, India is a large importer of the various fertilizers and farmers receive subsidies from the government for this purpose. Note that supporting minimal *yields per acre* has been part of government policies in direction of the agricultural sector across developing countries like India and Africa and developed countries like the US or Europe. Improving the water system (see Geman, 2007) and using fertilizers are the two major ways of increasing the world production of food commodities.

2.2. Fertilizer, corn and wheat price trajectories over the period 1991 to 2012

Figure 2.1 displays the individual trajectories of the three fertilizer indexes as of 1991. The first graph represents the price of FAS phosphate rock cleared for export in the port of Casablanca (and ready to be lifted to the vessel, as FAS stands for “free alongside ship”) - Morocco is the biggest producer of phosphate rock. The second graph is the FOB urea Black Sea, Yuzhnyy harbor (FOB stands for Free on Board: the good is loaded on board the vessel nominated by the buyer; costs of insurance and freight are shared by the buyer and seller) - The Black Sea is a major source of urea. The third graph exhibits FOB potash, standard grade, available in Vancouver, with Canada being the biggest producer of potash. In the three cases, the fertilizer index is observed in a major producing country. Fertilizer prices have increased steadily since the end of 2002, with an historic peak in 2008 that occurred almost simultaneously for the three types of fertilizers.

We now turn to the behavior of corn and wheat, two fundamental commodities that need a large amount of fertilizers, and the World Fertilizer Index over the period January 1991 to December 2012.

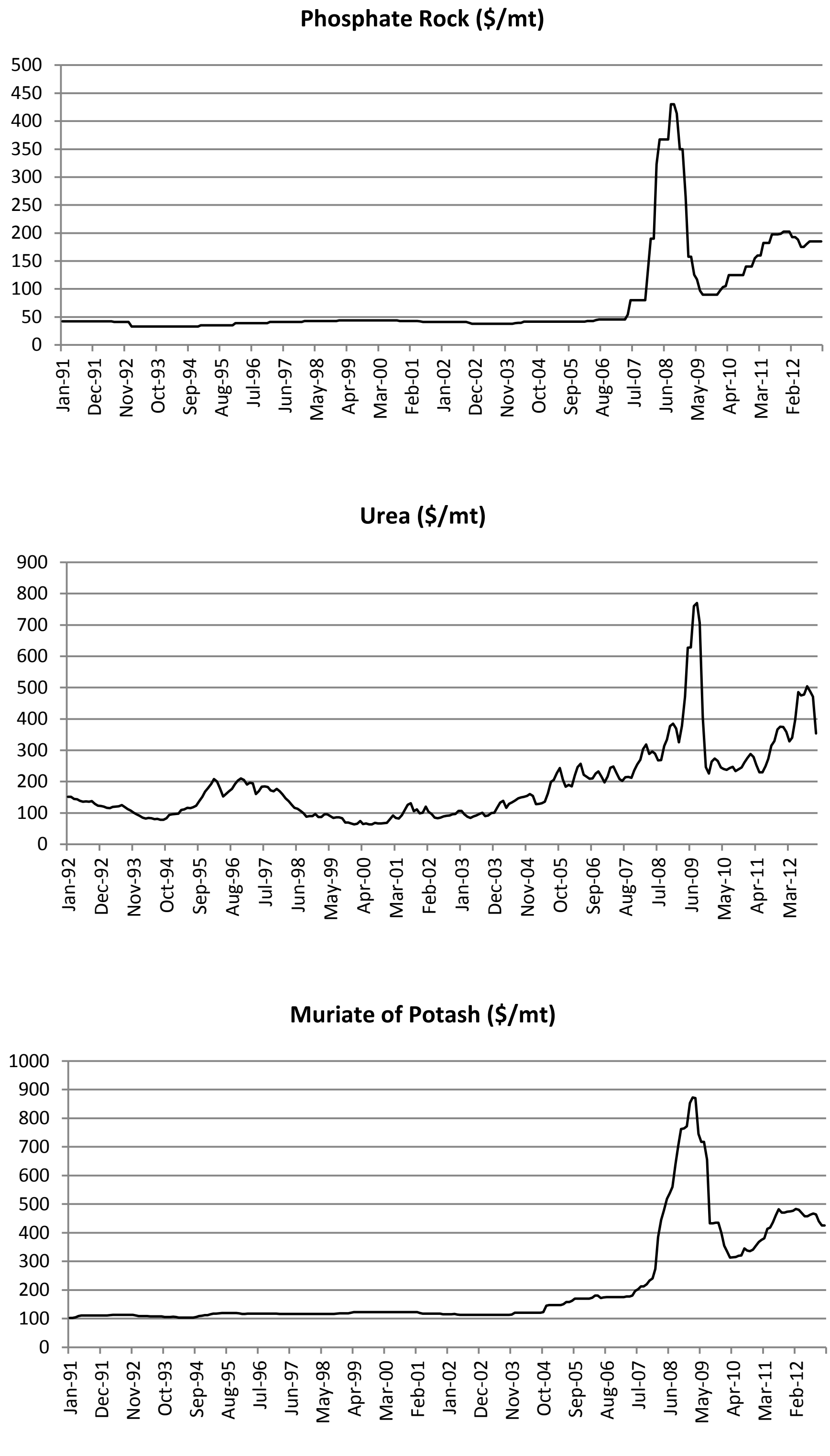


Figure 2.1. Trajectories of phosphate, urea and potash prices in US dollars per metric ton from January 1991 to December 2012

2.3. Data

Corn and wheat spot prices are represented by the CBOT first nearby Futures, expressed in cents per bushel. The Fertilizer Index monthly data have been obtained from the World Bank and monthly returns have been calculated in the standard way.

In all asset classes, volatility is an important quantity. In the case of agricultural commodities it is crucial because it creates concerns amidst citizens and governments and it is transmitted along the agrifood supply chain. Geman and Nguyen (2005) show the effect of inventory on soybean price volatility by exhibiting on a large database a remarkable inverse relationship between the two, a result in agreement with the theory of storage. We can note that fertilizers belong to the group of storable commodities, both in their primitive form and across the various stages of the supply chain. Du et al. (2011) study volatility spill-over in agricultural commodity markets.

In order to study the evolution of the volatility of corn and wheat, we use the annualized volatility of daily returns over one-month periods. For each commodity, we use daily prices to obtain daily returns; then, we calculate the volatility from daily returns over one-month periods. Finally, we annualize this volatility to obtain a time series of a monthly frequency of annualized volatilities of daily returns.

The volatility for agricultural commodity *j* in month *m* is calculated as

$$Volatility_{jm} = \sqrt{\frac{1}{n_m-1}\sum_{i=1}^{n_m}\left(\Delta \ln p_{jmi} - \frac{1}{n_m}\sum_{i=1}^{n_m}\Delta \ln p_{jmi}\right)^2} \quad (1)$$

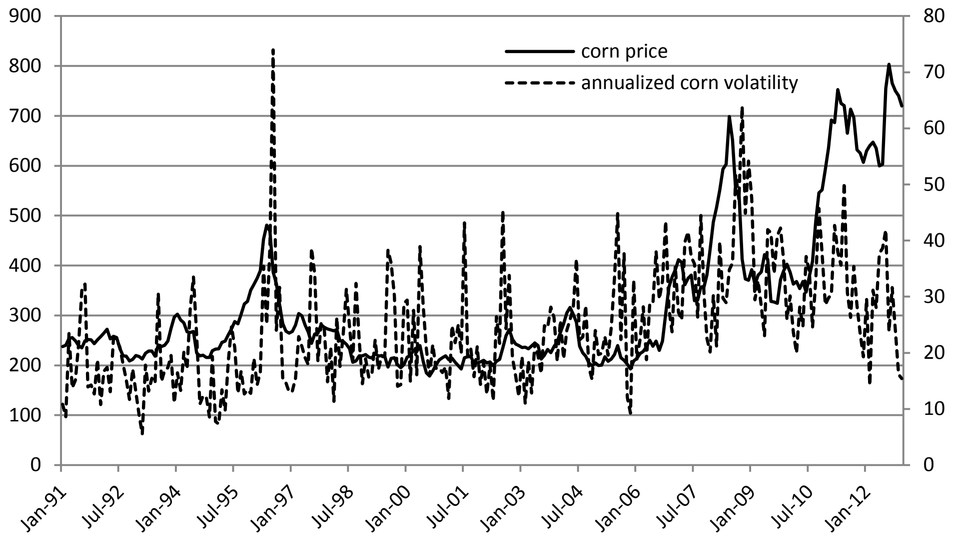
where p_{jmi} is the dollar value of the CBOT closing price of commodity *j* nearby Future contract on day *i* of month *m* and n_m is the number of days of trading on month *m*. It is annualized, as usual, in the tables below.

Table 2.2
Average annualized monthly volatilities (%) and descriptive statistics for CBOT corn and wheat from 1991 to 2012

Average Annualized Monthly Volatilities (%)		
Years	**Corn**	**Wheat**
1991-93	16.702	21.631
1994-96	19.654	22.528
1997-99	22.186	23.961
2000-02	21.646	24.292
2003-05	23.049	27.461
2006-08	33.616	36.686
2009-11	32.828	37.810
2012	27.685	30.876
Entire Period	24.397	27.908

Descriptive Statistics of Annualized Monthly Volatilities from 1991 to 2012		
	Corn	**Wheat**
Mean:	24.397	27.908
St. Dev.:	10.482	10.206
Skewness:	1.031	1.208
Kurtosis:	4.683	4.776

In the case of corn and wheat, the periods 2006-08 and 2009-12 stand out for exhibiting the highest volatility. As shown in Table 2.2, both volatility distributions display positive skewness and excess kurtosis. In the case of log volatility, standard sample skewness and kurtosis have been reduced, making normality a more acceptable assumption – a property that will allow us to use the Bai and Perron (2003) technique for the detection of breaks.



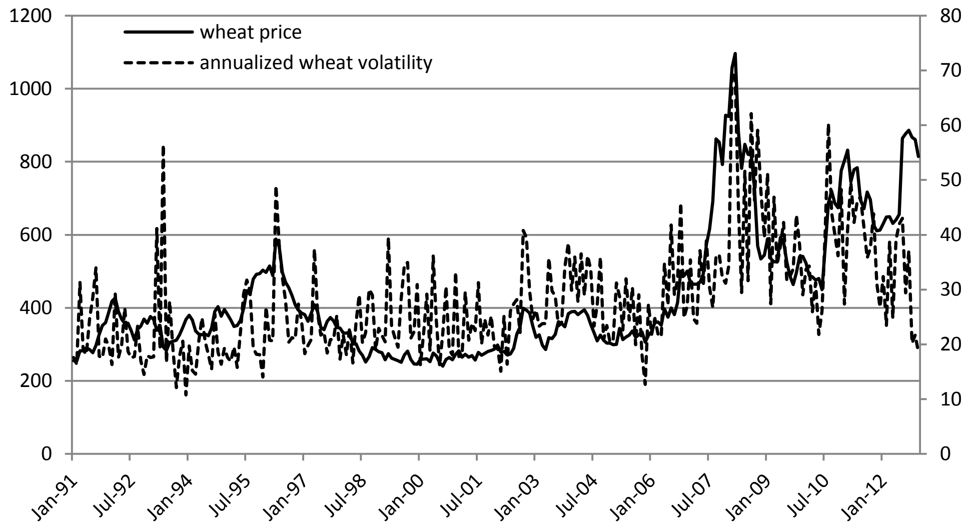


Figure 2.2. Top: CBOT corn prices and annualized corn volatility; bottom: CBOT wheat prices and annualized wheat volatility, from January 1991 to December 2012

Given the spectacular changes in prices and volatilities of corn and wheat between the years 1991-1993 and 2006-2008, for instance (see Figure 2.2), we decided to look for breaks in the trajectories of these four quantities over the period 1991-2012. In this order, we use the Bai and Perron (2003) algorithm to recognize the main break that explained the dramatic changes between the periods 1991-1993 and 2006-2008 and is identified by the largest reduction of the BIC (Bayes Information Criterion).

Table 2.3.

Structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log volatility series for CBOT corn and wheat, from January 1991 to December 2012. Year with month in parentheses.

Breakpoints:	**Corn**	**Wheat**
m = 1	2006(4)	2006(4)
m = 2	1996(3) 2006(4)	2002(4) 2007(8)
m = 3	1996(3) 2003(4) 2006(5)	1995(4) 2002(4) 2007(8)
m = 4	1996(3) 2000(6) 2003(7) 2006(8)	1995(4) 1999(3) 2002(4) 2007(8)
m = 5	1996(2) 1999(3) 2002(4) 2005(5) 2008(6)	1995(4) 1998(5) 2001(6) 2004(7) 2007(8)

Confidence intervals:	**Corn**			**Wheat**		
	2.5 %	**breakpoints**	**97.5 %**	**2.5 %**	**breakpoints**	**97.5 %**
Optimal 2-segment partition	2006(1)	2006(4)	2006(11)	2005(12)	2006(4)	2006(8)
Optimal 3-segment partition	1995(2)	1996(3)	1997(5)	2001(6)	2002(4)	2003(7)
	2005(12)	2006(4)	2006(12)	2007(1)	2007(8)	2008(2)
Optimal 4-segment partition	1994(11)	1996(3)	1997(7)	2007(1)	2007(8)	2008(2)
	1993(9)	2003(4)	2018(10)*	2000(10)	2002(4)	2004(1)
	2005(11)	2006(5)	2007(1)	2007(1)	2007(8)	2008(2)

Firstly, we use the Bai and Perron algorithm, for one to five structural breaks in the volatility time series, in order to test the assumption of changes in the mean of volatility and log volatility time series. Although the results of the test do not differ substantially in the break dates, we refer to the set of results provided by log volatility. Moreover, the assumption that requires the data to be a weakly stationary stochastic process can be substantially relaxed, since the log volatility provides us with a time series that is closer to the set of assumptions required by the test (closer to normality as Jarque Bera results suggest). Problems with the test due to heteroskedasticity of the series, i.e. non constant volatility of volatility in our case, should not be of concern as long as there are enough samples in each partition. Hence, the higher the number of partitions, the less optimal the result of break dates. In the presence of serial correlation, the test can be improved using lagged variables. Additional to the set of results presented in this section, we have also studied up to lag 12 with no outstanding differences.

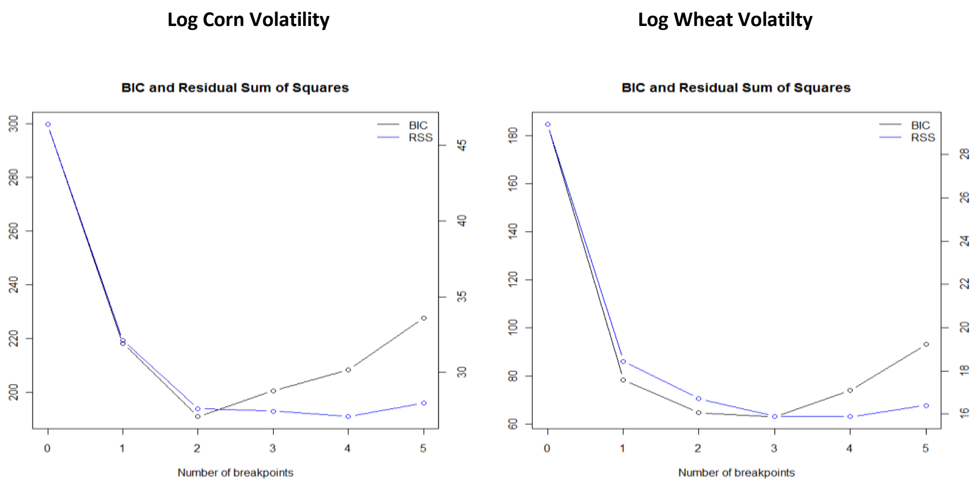


Figure 2.3. BIC and residual sum of squares for the structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log volatility series for CBOT corn and wheat, from January 1991 to December 2012.

We report the Residual Sum of Squares (RSS) and the Bayesian Information Criterion (BIC) in Figure 2.3. In general, the BIC is a superior selection criterion to select the optimal number of breaks, except when there is a lagged dependent variable in the model. We also compute the confidence intervals following Bai (1997) for the optimal number of breaks.

In the case of commodities, it is fundamental to look at price levels. In order to select a relevant number of breaks, we study each price series and how they relate to volatility. We repeat the previous analysis of structural breaks for the case of log prices of the three commodities. As before, we are interested in changes in price and refer to the log price results since they are closer to the assumptions necessary for the Bai and Perron tests.

Table 2.4

Structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log prices for CBOT corn and wheat, from January 1991 to December 2012. Year with month in parentheses.

Breakpoints:	Corn	Wheat
m = 1	2006(10)	2006(9)
m = 2	1998(5) 2006(10)	1997(12) 2006(9)
m = 3	1995(4) 1998(5) 2006(10)	1998(3) 2002(6) 2006(9)
m = 4	1995(4) 1998(5) 2002(6) 2006(10)	1994(8) 1997(12) 2002(6) 2006(9)
m = 5	1994(1) 1997(5) 2000(6) 2003(8) 2006(10)	1994(8) 1997(10) 2000(11) 2003(12) 2007(4)

Confidence intervals:	Corn			Wheat		
	2.5 %	**breakpoints**	**97.5 %**	**2.5 %**	**breakpoints**	**97.5 %**
Optimal 2-segment partition	2006(7)	2006(10)	2006(11)	2006(7)	2006(9)	2006(10)
Optimal 3-segment partition	1998(1)	1998(5)	1999(5) (1)	1997(6)	1997(12)	1998(10)
	2006(8)	2006(10)	2006(11)	2006(7)	2006(9)	2006(10)
Optimal 4-segment partition	1994(8)	1995(4)	1995(6)	1998(2)	1998(3)	1998(7)
	1998(3)	1998(5)	1998(9)	2002(4)	2002(6)	2002(7)
	2006(8)	2006(10)	2006(11)	2006(7)	2006(9)	2006(10)

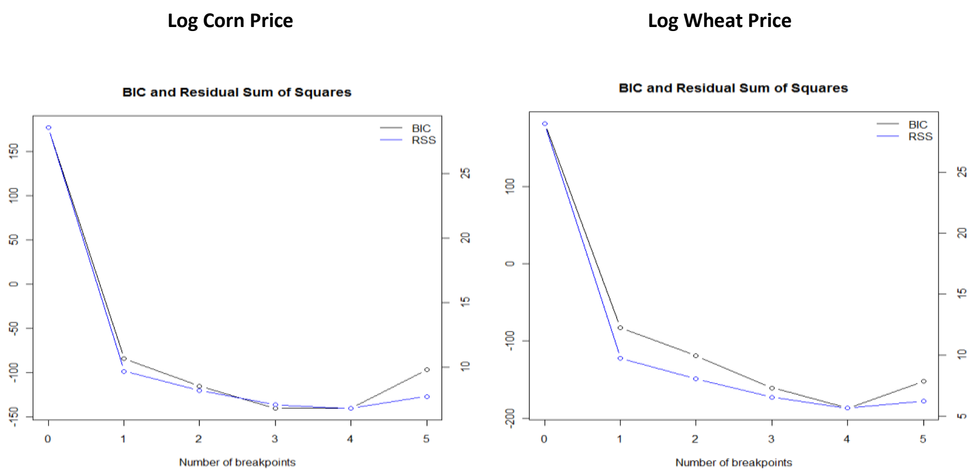


Figure 2.4. BIC and residual sum of squares for structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log prices for CBOT corn and wheat, from January 1991 to December 2012.

Table 2.5

Structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log prices and returns for fertilizers, from January 1991 to December 2012. Year with month in parentheses.

Breakpoints	Fertilizer Returns	Log Fertilizer Price
m = 1	2008(8)	2007(4)
m = 2	2005(7) 2008(8)	2004(6) 2007(9)
m = 3	2002(4) 2005(7) 2008(8)	1994(8) 2004(6) 2007(9)
m = 4	1996(3) 2002(4) 2005(7) 2008(8)	1994(8) 1997(9) 2004(6) 2007(9)
m = 5	1994(2) 1997(3) 2002(4) 2005(7) 2008(8)	1994(8) 1997(9) 2001(5) 2004(6) 2007(9)

Confidence intervals:	**Fertilizer Returns**			**Log Fertilizer Price**		
	2.5 %	**breakpoints**	**97.5 %**	**2.5 %**	**breakpoints**	**97.5 %**
Optimal 2-segment partition	2001(6)	2008(8)	2010(5)	2007(2)	2007(4)	2007(5)
Optimal 3-segment partition	2003(5)	2005(7)	2005(11)	2004(4)	2004(6)	2004(7)
	2007(5)	2008(8)	2009(8)	2007(6)	2007(9)	2007(10)
Optimal 4-segment partition	1996(11)	2002(4)	2005(2)	1993(8)	1994(8)	1995(8)
	2001(9)	2005(7)	2006(4)	2004(4)	2004(6)	2004(7)
	2007(5)	2008(8)	2009(8)	2007(6)	2007(9)	2007(10)
Optimal 5-segment partition	1983(9)	1996(3)	2008(12)	1994(6)	1994(8)	1994(11)
	1998(8)	2002(4)	2004(2)	1997(7)	1997(9)	1997(12)
	2001(9)	2005(7)	2006(4)	2004(4)	2004(6)	2004(7)
	2007(5)	2008(8)	2009(8)	2007(6)	2007(9)	2007(10

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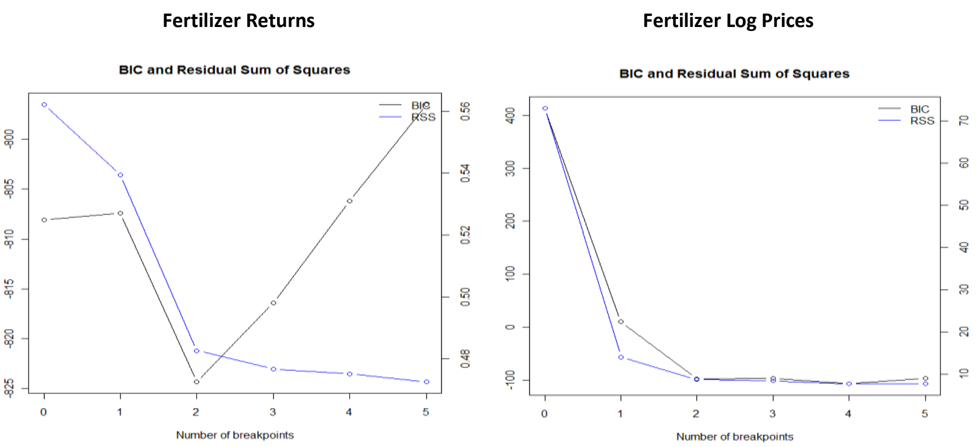


Figure 2.5. BIC and residual sum of squares for structural breaks analysis with five breaks (m=1 to m=5) in the annualised monthly log prices and returns for fertilizers, from January 1991 to December 2012.

In all cases, we can clearly see that the first break achieves the highest reduction in the BIC and acted as a signal to investors, i.e., this break marks the point which changes the face of fertilizer markets from unknown to desirable. Hence, from here onwards, we present our results based on a unique structural break that, apart from allowing the highest reduction in BIC, gives us enough data in each partition for any future analysis. In Figure 2.7, the results of the Bai and Perron algorithm for corn with one break are displayed. We find that the structural break in the corn price trajectory occurs in October 2006 with a confidence interval ranging from August to November 2006; and in April 2006 with a confidence interval ranging from December 2005 to November 2006 for its log volatility (wider in the latter case because of the averaging process involved in volatilities). For wheat prices (see Figure 2.8), we find a structural break in September 2006 with a confidence interval ranging from July to October 2006 and a structural break in April 2006 for the wheat volatility, with a confidence interval ranging from November 2005 to September 2006. In the case of corn log prices, the break reduces the BIC value from 246.6 to - 56.2; in the case of wheat log price, from 219.8 to - 85.2.

Figure 2.6 depicts the results for the Fertilizer Index log prices. Since the Fertilizer Index prices are provided by the World Bank with a monthly frequency, in Table 2.6 we exhibit the annualized volatility of monthly returns in each year. It allows us to see a remarkable peak of nearly 50% in 2008, up from values around 5% in the years 1998 and 1999.

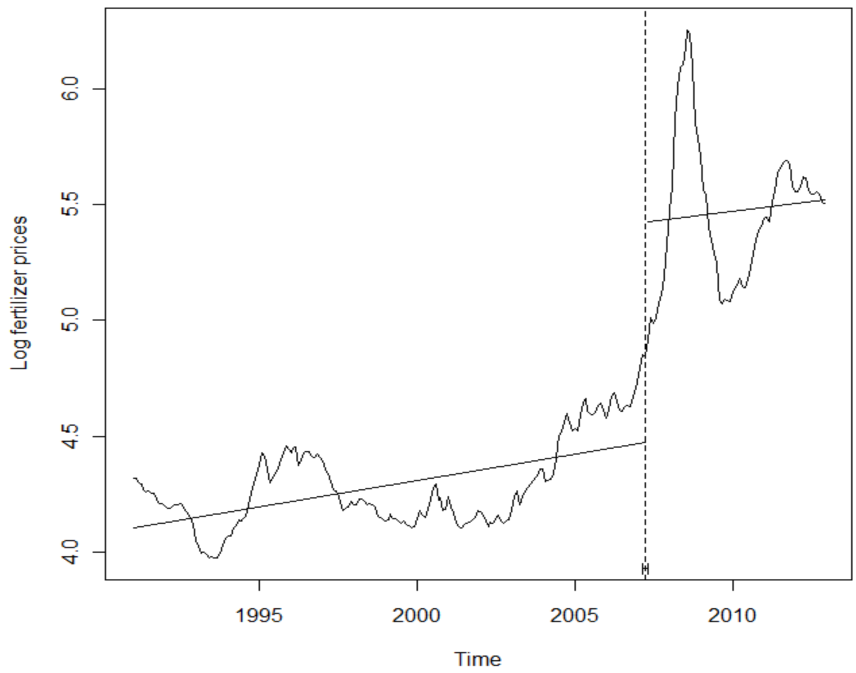


Figure 2.6. Monthly average Fertilizer Index log prices with one structural break, from January 1991 to December 2012

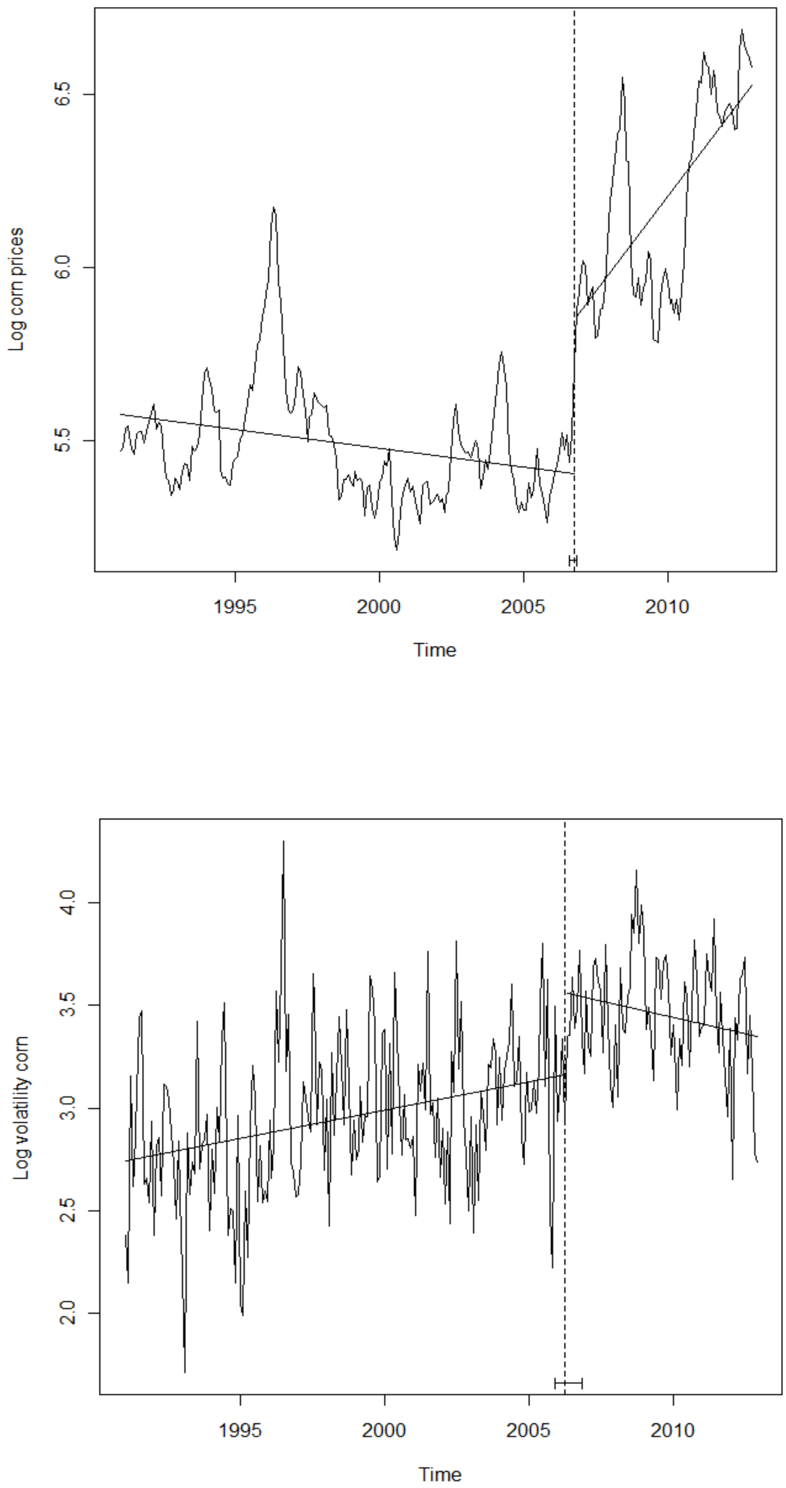
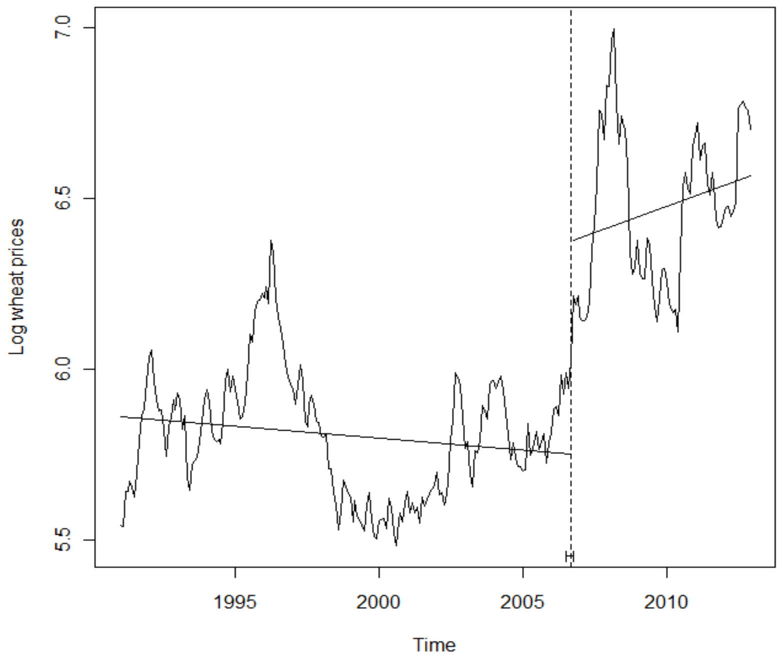


Figure 2.7. Monthly average corn log prices and log volatility with one structural break, from January 1991 to December 2012



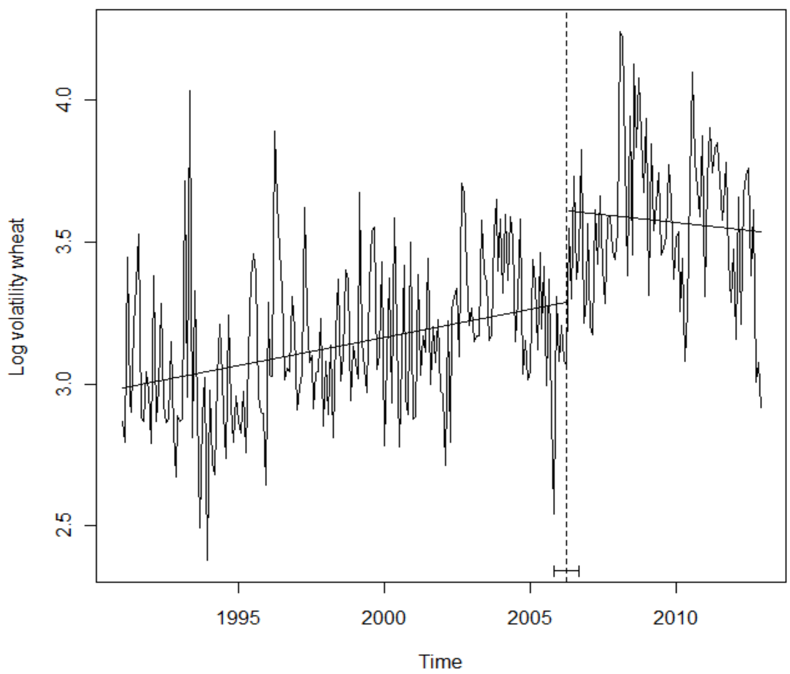


Figure 2.8. Monthly average wheat log prices and log volatility with one structural break, from January 1991 to December 2012

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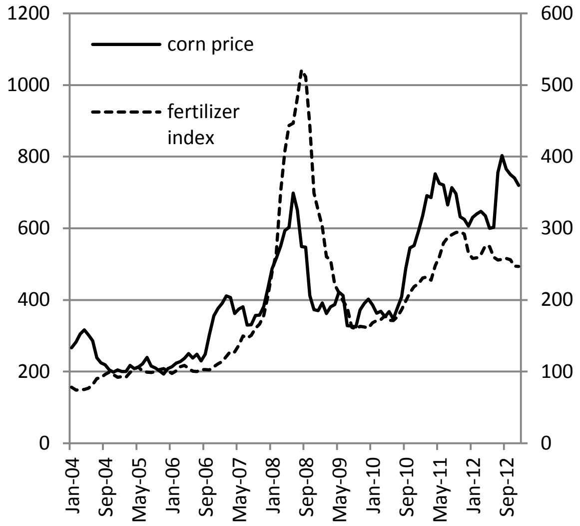
Table 2.6
Annualized volatility in percentage terms of monthly returns of the Fertilizer Index, CBOT Corn, and CBOT Wheat, from 1991 to 2012

Year	Fertilizers	Corn	Wheat	Year	Fertilizers	Corn	Wheat
1991	3.77	11.50	16.46	**2002**	6.02	17.44	28.49
1992	3.69	15.45	20.94	**2003**	9.58	23.62	26.65
1993	10.02	16.75	25.88	**2004**	15.28	32.87	19.11
1994	6.52	19.98	20.03	**2005**	11.76	29.60	28.94
1995	12.63	9.94	19.00	**2006**	11.47	26.58	20.66
1996	10.12	32.85	26.26	**2007**	14.98	33.91	37.21
1997	6.82	18.85	18.99	**2008**	48.97	47.29	42.54
1998	5.36	16.05	18.75	**2009**	21.26	34.87	39.98
1999	4.63	16.69	17.05	**2010**	9.67	37.47	48.54
2000	13.22	26.19	22.29	**2011**	16.16	40.16	43.52
2001	9.84	20.40	20.39	**2012**	8.94	34.56	26.03

We also observe a rise in fertilizer volatility as of 2004. Accordingly, the Bai and Perron algorithm exhibits a structural break for the fertilizer index log price in April 2007, with a confidence interval ranging from March 2007 to May 2007.

The remarkable synchronicity of the breaks in corn and wheat price trajectories is in agreement with the substitutability between these two commodities which are central in the production of bread, cereals, feedstock and human food. Wang and Tomek (2007) show that structural breaks in commodity prices are influenced by changes in farm price, trade policies and other factors that result in a systematic behaviour of prices, while Worthington and Pahlavani (2006) find other reasons for the appearance of structural breaks in commodities, such as economic crises and changes in institutional arrangements. The fact that the break in the fertilizer index price trajectory took place some months after corn and wheat could reflect the delayed price increase of fertilizers decided by producing companies facing a rising demand from farmers worldwide in a search for better productivity in the next harvest. The related effects between corn, wheat and fertilizer index price movements are displayed in Figure 2.9.



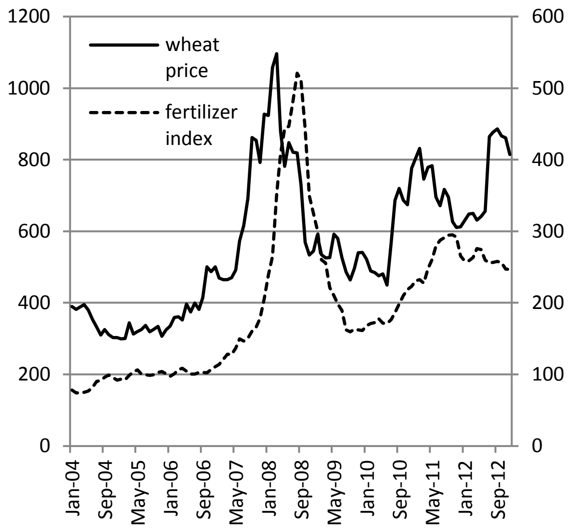


Figure 2.9. Quasi-contemporaneous effects between corn, wheat (left axis) and Fertilizer Index prices (right axis), from January 2004 to December 2012

3. Fertilizer Producing Companies and Share Price Returns over the Period Jan 2004 to Dec 2012

For this part of our investigation, we study a sample comprising *all* fertilizer firms selected on the two criteria of being traded on an Exchange (for instance, Office Chérifien des Phosphates is quite an important company, but state-owned, hence outside our sample), and being primarily involved in activities related to the extraction and production of all types of fertilizers. During the period from 2008 to 2012, the Russian company Uralkali that had come to existence was added.

Investors who wished to gain exposure to commodities over the last decade, during which commodity prices were much higher than in the 1990s, first had the choice between buying Futures contracts on individual commodities and passively investing in commodity indexes such as the GSCI Commodity Index (for instance, see Geman, 2005). Another possible way to benefit from a rise in gold or crude oil prices was to buy shares of gold mining or oil companies. In the case of fertilizers, no investment commodity index as of today contains phosphate or potash as a component, and fertilizers are not traded on an Exchange. Hence, the purchase of shares of fertilizer-related companies still represents the primary means of getting exposure to fertilizer prices – except for swaps related to fertilizer indexes which are only traded by the industry and some experts.

In Table 2.7, we display a list of all listed fertilizer companies, together with the countries where they are incorporated and their main activities.

Table 2.7

Fertilizer firms' location and activities

Company Name	Country	Fertilizer Interests
Rosier S.A.	Belgium	P&D
Fosfertil /Vale	Brazil	Supply of raw materials and intermediate products.
Spur Ventures Inc.	Canada	Development of two large phosphate deposits in China.
Agrium Inc.	Canada	P&D. Owner of phosphate and potash mines.
PotashCorp./Saskatchewan Inc.	Canada	P&D. Owner of phosphate and potash mines.
SQM	Chile	Extensive mining operations.
Abu-Qir Fertilizers & Chemical Ind. Co.	Egypt	P&D
E.F.I.C. - Egyptian Financial & Industrial Co.	Egypt	P&D
K + S	Germany	P&D and extraction of raw materials.
Sinofert Holdings Ltd	Hong Kong	P&D
Mangalore Chemicals & Fertilizers	India	P&D
Nagarjuna Frtz & Chem	India	P&D
National Fertilizers Ltd	India	P&D
Zuari Industries Ltd	India	P&D
ICL	Israel	Mining interests across the world.
AB Lifosa	Lithuania	P&D
Yara International	Norway	P&D
Dawood Hercules Chemicals Ltd	Pakistan	P&D
Fauji Fertilizer Company Ltd	Pakistan	P&D
SAFCO - Saudi Arabian Fertilizer Company	Saudi Arabia	P&D
Sesoda Corp.	Taiwan	P&D
Taiwan Fertilizer Co.	Taiwan	P&D
Bagfas Bandirma Fabrikalari	Turkey	P&D
Gübre T.A.S.	Turkey	P&D
Andersons	US	P&D
Compass Minerals Intl.	US	Operates mines and produces specialty fertilizer.
LSB INDS.	US	Wholesale and retail trade.
Terra Nitrogen Company	US	P&D
Mosaic Company	US	P&D. Owner of phosphate and potash mines.

Note: P&D denotes fertilizer production and distribution with no known mining interests

We chose the years 2004 to 2012 to conduct a performance study because this time period provided the *largest* number of listed fertilizer mining companies. Moreover, the interval 2004-2012 has the merit of being symmetric with respect to the financial crisis of 2008, which had an impact on all asset classes. In order to screen the return on the capital invested in the fertilizer industry, we propose to analyze the positioning of the fertilizer share returns with respect to the Security Market Line (SML) exhibited in the Capital Asset Pricing Model (CAPM) in a standard way. The CAPM is widely used by corporations for capital structure and budgeting decisions. Da et al. (2012) provide empirical support for the continuous use of the CAPM model, even if at times the CAPM has been deemed obsolete. Brown and Walter (2013) also emphasize the popularity of the CAPM amongst researchers and practitioners today due to the fact that it provides a very intuitive way of thinking about the risk/return trade-offs.

Given the diversity of countries in the picture, we split our sample into two sub-samples, companies located in developed countries versus companies in developing countries – again, a compromise had to be reached between the fine features and the size of the sample. In the first case, the MSCI World Index (appropriate for countries like the US, Norway, Germany) was chosen as the reference equity benchmark index, while the MSCI - EM (Morgan Stanley Composite Index - Emerging Countries) was chosen for the second case. The intercept of the Security Market line with the vertical axis is the ‘risk-free rate’, which we represent with the 3-month T-bill in the case of developed countries, and with the Overnight Index Swap (OIS) for the emerging countries. All of our data is sourced from Reuters Datastream.

According to the CAPM, when the Security Market Line (SML) is ‘at equilibrium,' all of the points lie on the SML (beta, expected return), where the beta of firm *i* is defined by $\beta_i = Cov(R_i, R_b) / Var(R_b)$. We compute the betas through the linear regression $R_i = a_i + \beta_i R_b + \varepsilon$, where R_i is the monthly return on stock *i* and R_b is the return of the equity benchmark index. For the vertical coordinates, we compute the mean returns as an average of annualized monthly returns over each period, as in Grinblatt and Titman (1998).

Over the first period, Jan 2004 to Dec 2007, the SML was mildly increasing in the case of US firms, with a higher slope for non-US ones. All US listed firms provided very high betas. Mosaic and Potash Corp displayed absolute returns higher than 50% and alphas in the order of 40%, returns that are outstanding during any time period. The lowest return, given by Compass Minerals, has an alpha of 15%.

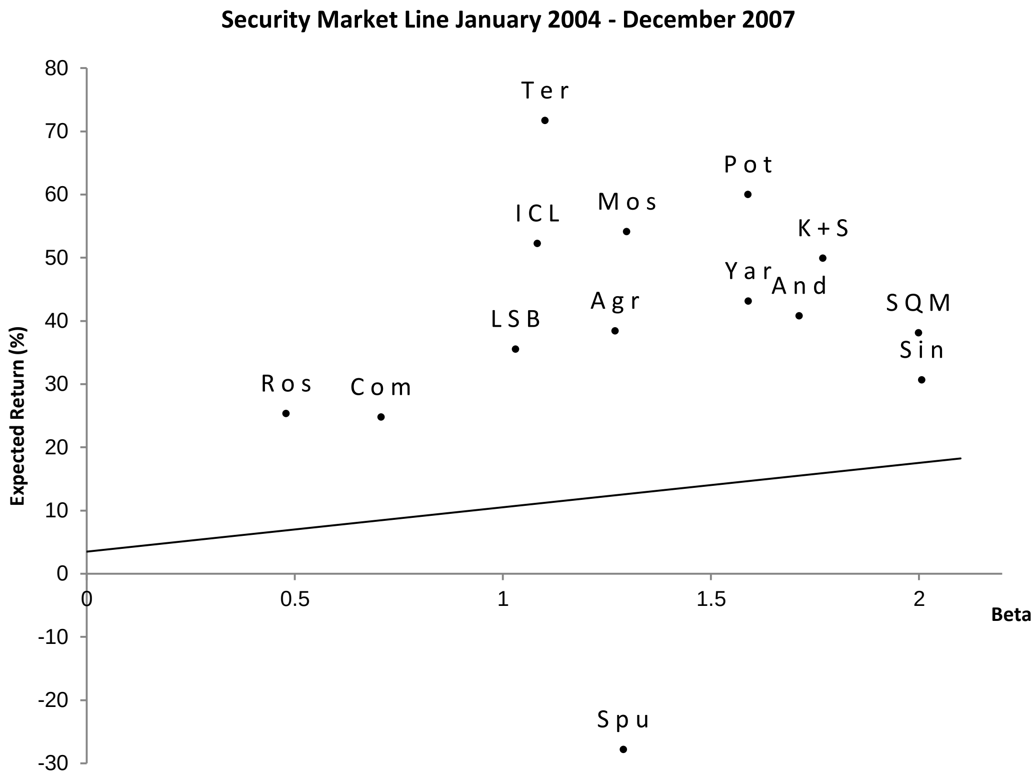
During the period Jan 2008 to Dec 2012, which covers both the financial crash and the subsequent recovery, the average SML was declining in both cases and exhibited an intercept with the vertical axis close to zero because of the levels of short term rates. From Figure 2.10, we see that most fertilizer companies continued to do remarkably well, with an alpha of 30% for SQM from Chile, which is traded on the NYSE, and 15% for Agrium. K+S and Potash performed in agreement with their betas. We note that the alphas did not go to the levels reached when fertilizers first became known to the financial world. In 2010, Potash was the subject of an all-cash hostile takeover by the Australian mining giant BHP Billiton. The offer was rejected by Potash, while the whole bidding process was under the scrutiny of the Canadian Energy and Resources Ministry. The combined capabilities of Canada's Potash in potash, phosphate and nitrogen make it the world's largest fertilizer company by capacity, while US company Mosaic is the second largest (Yara International is the world's largest producer of nitrogen-based fertilizers).

Table 2.8
Betas and returns of the first group of companies over the two periods

Stock Index Used: MSCI World	Symbol	Jan 2004 to Dec 2007	
Company		**Beta**	**Returns (%)**
Rosier S.A.	R o s	0.48	25.39
Spur Ventures Inc.	S p u	1.29*	-27.75
K + S	K+S	1.77***	49.95
Sinofert Holdings Ltd	S i n	2.01**	30.7
ICL	I C L	1.08***	52.3
Yara International	Y a r	1.59***	43.18
Agrium Inc.	A g r	1.27**	38.48
PotashCorp./Saskatchewan Inc.	P o t	1.59***	60.04
SQM	S Q M	2***	38.14
Andersons	A n d	1.71**	40.84
Compass Minerals Intl.	C o m	0.71**	24.84
LSB INDS.	L S B	1.03	35.59
Terra Nitrogen Company	T e r	1.1	71.75
Mosaic Company	M o s	1.3**	54.16

Stock Index Used: MSCI World	Symbol	Jan 2008 to Dec 2012	
Company		**Beta**	**Returns (%)**
Rosier S.A.	R o s	0.42*	-2.72
Spur Ventures Inc.	S p u	1.06***	-7.87
K + S	K+S	1.46***	-2.82
Sinofert Holdings Ltd	S i n	0.67**	-24.24
ICL	I C L	1.18***	-0.65
Yara International	Y a r	1.55***	1.45
Agrium Inc.	A g r	1.64***	8.92
PotashCorp./Saskatchewan Inc.	P o t	1.23***	-2.9
SQM	S Q M	0.86***	23.99
Andersons	A n d	1.5***	-1.22
Compass Minerals Intl.	C o m	0.49**	11.5
LSB INDS.	L S B	1.75***	5.25
Terra Nitrogen Company	T e r	0.78**	9.08
Mosaic Company	M o s	1.58***	-9.63

Note: ***, **, and * denotes significance at the 1%, 5% and 10% level, respectively



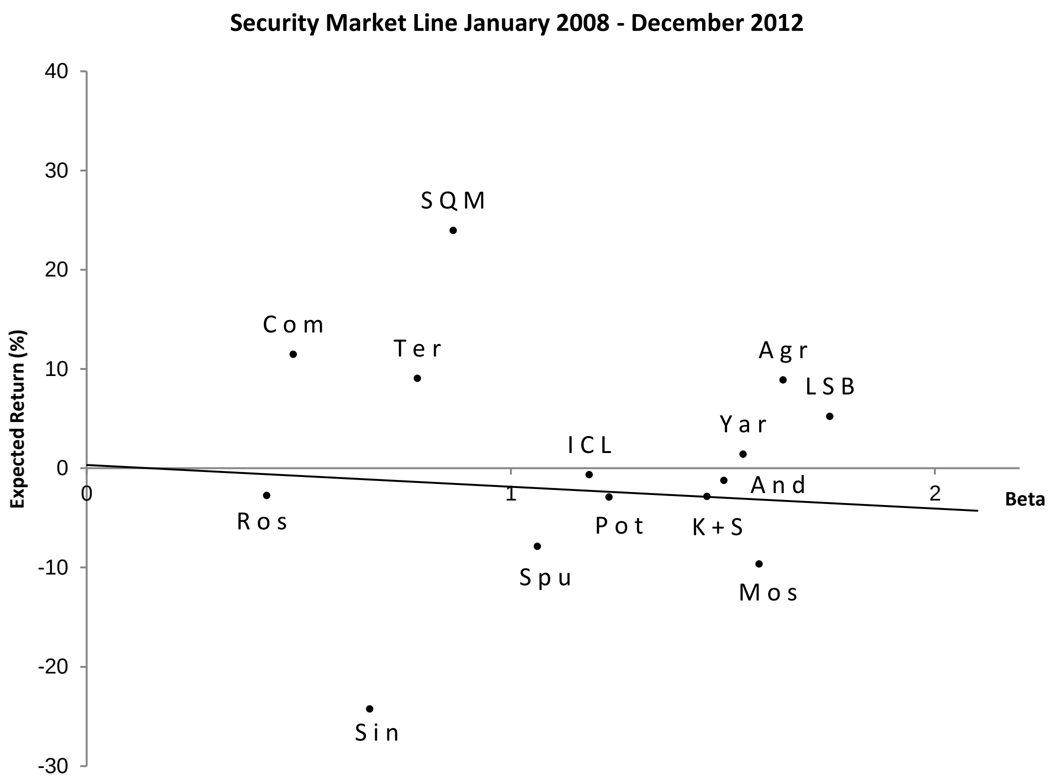


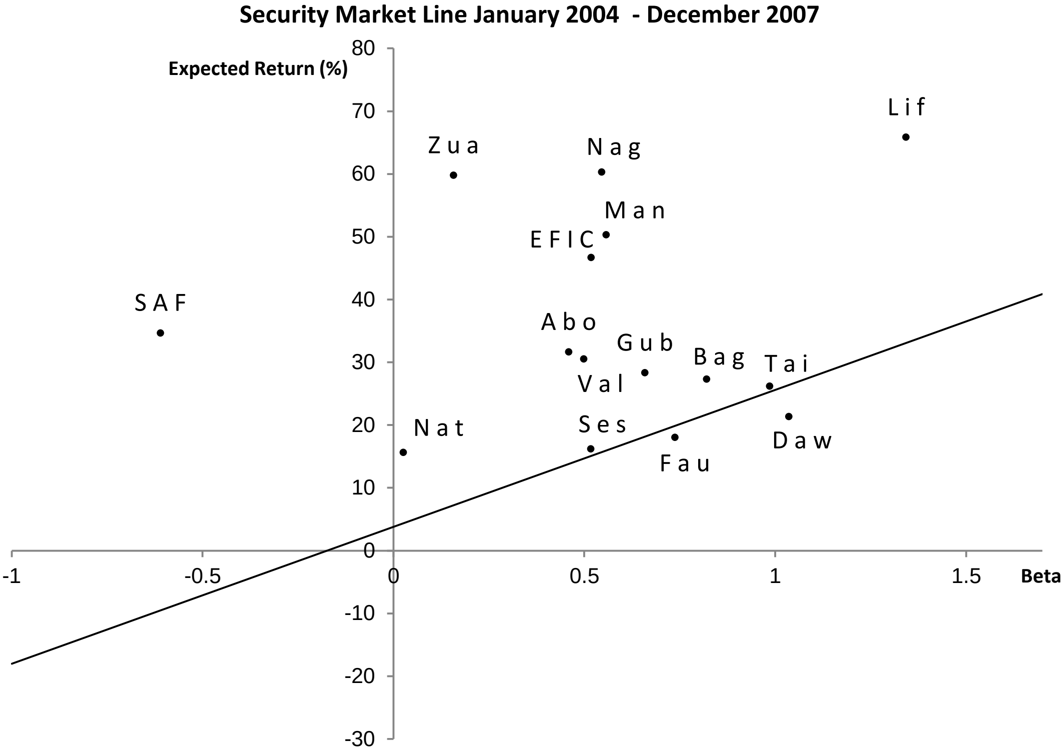
Figure 2.10. Security Market Lines of fertilizer firms in developed countries

Table 2.9
Betas and Returns of the second group over the two periods

Stock Index Used: MSCI- EM	Symbol	Jan 2004 to Dec 2007	
Company		**Beta**	**Returns (%)**
Fosfertil (Vale Fertilizantes S.A.)	V a l	0.5**	30.55
Abu-Qir Fertilizers & Chemical Ind. Co.	A b o	0.46*	31.68
E.F.I.C.-Egyptian Financial & Industrial Co.	E F I C	0.52	46.71
Mangalore Chemicals & Fertilizers	M a n	0.56	50.32
Nagarjuna Frtz & Chem	N a g	0.55	60.33
National Fertilizers Ltd	N a t	0.03	15.67
Zuari Industries Ltd	Z u a	0.16	59.82
AB Lifosa	L i f	1.34**	65.87
Dawood Hercules Chemicals Ltd	D a w	1.03***	21.39
Fauji Fertilizer Company Ltd	F a u	0.74***	18.1
SAFCO - Saudi Arabian Fertilizer Company	S A F	-0.61	34.72
Sesoda Corp.	S e s	0.52**	16.24
Taiwan Fertilizer Co.	T a i	0.98***	26.22
Bagfas Bandirma Fabrikalari	B a g	0.82***	27.36
Gübre T.A.S.	G u b	0.66*	28.37

Stock Index Used: MSCI- EM	Symbol	Jan 2008 to Dec 2012	
Company		**Beta**	**Returns (%)**
Fosfertil (Vale Fertilizantes S.A.)	V a l	0.64***	8.85
Abu-Qir Fertilizers & Chemical Ind. Co.	A b o	0.36*	-7.06
E.F.I.C.-Egyptian Financial & Industrial Co.	E F I C	1.21***	-23.14
Mangalore Chemicals & Fertilizers	M a n	0.87***	5.35
Nagarjuna Frtz & Chem	N a g	1.35***	-12.01
National Fertilizers Ltd	N a t	1.14***	5.95
Zuari Industries Ltd	Z u a	1.35***	10.23
AB Lifosa	L i f	0.81***	-3.99
Dawood Hercules Chemicals Ltd	D a w	0.32	-15.64
Fauji Fertilizer Company Ltd	F a u	-0.06	-2.37
SAFCO - Saudi Arabian Fertilizer Company	S A F	0.83***	5.54
Sesoda Corp.	S e s	1.01***	9.18
Taiwan Fertilizer Co.	T a i	1.16***	-6.53
Bagfas Bandirma Fabrikalari	B a g	0.67***	8.88
Gübre T.A.S.	G u b	0.69***	32.24
Uralkali	U r a	1.25***	8.18

Note: ***, **, and * denotes significance at the 1%, 5% and 10% level, respectively



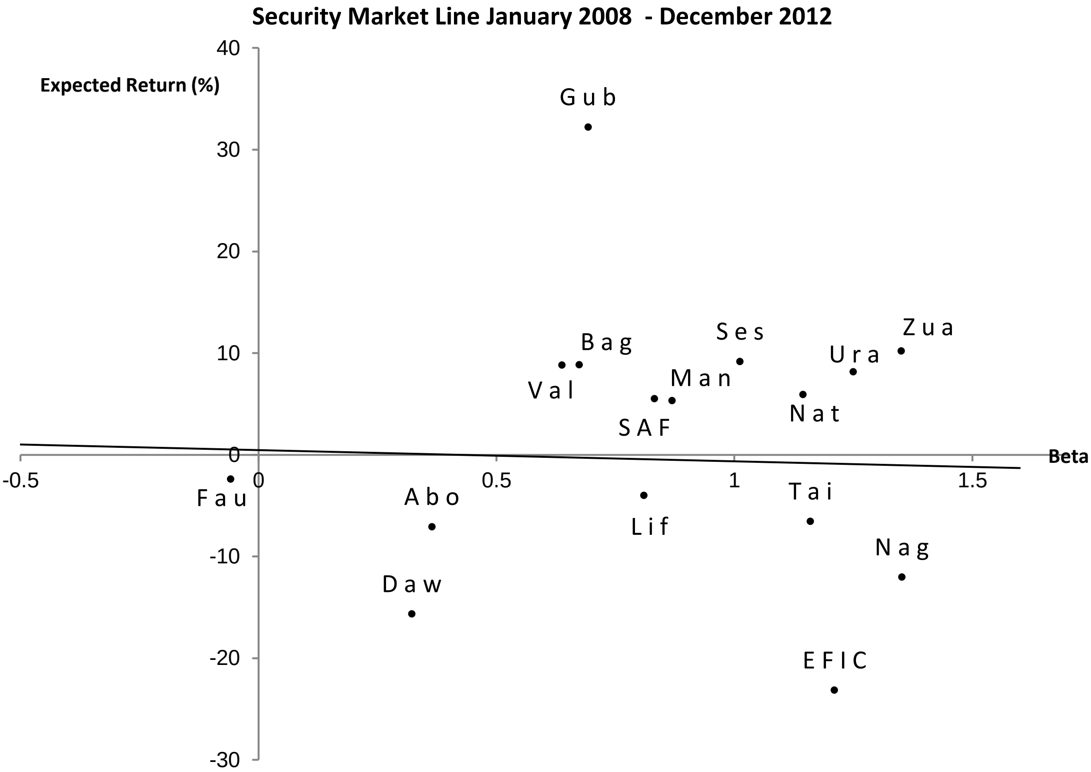


Figure 2.11. Security Market Lines of emerging market firms over the two periods

The results for the firms depicted in Figure 2.11 are of the same nature for the first period as the ones depicted in Figure 2.10, with excess performances over the SML reaching 50% for Zuari and Nagarjuna. We obtain betas of approximately 50% for the companies K+S, ICL and EFIC. Together with EFIC, Sinofert also exhibited negative returns over the second period. The company Sinofert Holding is the largest fertilizer importer and distributor in China. It performed better than the market in the first period but had very poor results over the period Jan 2009 to Dec 2011. In fact, its operating profits became very negative in the first semester of 2009, in particular because the Chinese government imposed price controls on some fertilizers in 2008. The share price of Sinofert, traded in Hong Kong, has been continuously declining from a peak of eight HK dollars in 2008 to less than two dollars at the time of writing. It is worth noting that most betas are significant in the post-crisis period, with the exception of Dawood Hercules Chemicals Ltd and Fauji Fertilizer Company Ltd., both companies from Pakistan, a highly regulated market with a high government involvement.

To conclude this section, we observe that investing in shares of Mosaic, Agrium, Potash and other fertilizer-related companies during the period 2004 to 2012 was a very wise investment, and particularly if done in the early days when fertilizers first came to the attention of the agricultural finance world.

4. Sensitivities of Fertilizer Equities to Agricultural Prices

Pension funds and insurance companies, which have sold variable annuities to future retirees, need to hedge their exposure to inflation risk. Since food costs represent a significant part of inflation indexes, they may find a cheaper alternative to inflation derivatives by investing part of their free cashflows into agribusiness equity. Another choice is to buy shares of fertilizer companies. This motivates our interest in the sensitivities of these share returns to a major agricultural commodity basket represented by the Goldman Sachs Commodity Index Ags. We also include the World Fertilizer Index, which was presented in Section 2. This type of analysis is in line with Chance and Lance (1980), who examined the sensitivities of shares of financial institutions to interest rates. An abundant literature followed, which studied oil and gold mining companies' price sensitivities to the underlying commodity price. Strong (1991) studied the use of oil companies' portfolios to hedge oil price risk. Blose and Shieh (1995) considered 23 gold mining companies and presented an extension of the work by McDonald and Solnik (1977), who had investigated 26 South African and 10 American mining companies. In 1996, Brimelow analyzed the 'gold play' investors were getting from their mining stock investments. This section aims at extending this approach to the case of fertilizer companies.

As in Section 3, we look separately at developed versus emerging countries' listed firms. We use monthly prices in all cases since it is the frequency of publication of the World Bank Fertilizer Index and the agricultural index GSCI Ags is rebalanced a few times a year. Moreover, we have in mind investors who are motivated by a macroeconomic approach as opposed to a daily rebalancing of their holdings. We use one-factor regressions to calculate the sensitivities β_{ic} of each company

$$R_i = a_{ic} + \beta_{ic} R_c + \varepsilon \qquad (2)$$

where R_i is the monthly return on stock *i*, R_c is the monthly return on one of the three commodity indexes and the coefficient β_{ic} represents the sensitivity of stock return *i* to the commodity index return. Note that each of the three indexes is already itself a basket, besides being an observable quantity; hence multi-factor regressions would rather blur the message than bring extra-information.

Table 2.10
Thirty Fertilizer firms' sensitivities to the World Fertilizer Index and the GSCI Ags from Jan 2004 to Dec 2007

Whole Sample	From January 2004 to December2007			
30 Listed Fertilizer Firms	Fertilizer Index		GSCI Ags	
Rosier S.A.	0.45	***	0.04	
Fosfertil (Vale Fertilizantes S.A.)	0.4		0.18	
Spur Ventures Inc.	0.02		-0.02	
Agrium Inc.	0.58	**	0.33	
PotashCorp./Saskatchewan Inc.	0.17		0.41	*
SQM	-0.19		0.23	
Abu-Qir Fertilizers & Chemical Ind. Co.	0.02		0.13	
E.F.I.C.-Egyptian Financial & Industrial Co.	0.37		0.23	
K + S	0.22		0.3	
Sinofert Holdings Ltd	0.76	*	0.22	
Mangalore Chemicals & Fertilizers	-0.48		0.34	
Nagarjuna Frtz & Chem	0.1		0.86	**
National Fertilizers Ltd	0.74	*	0.45	
Zuari Industries Ltd	0.46		0.52	
ICL	-0.13		0.13	
AB Lifosa	-0.79		0.48	
Dawood Hercules Chemicals Ltd	-0.26		0.62	**
Fauji Fertilizer Company Ltd	-0.5		0.13	
SAFCO - Saudi Arabian Fertilizer Company	0.44		-0.4	
Sesoda Corp.	-0.83	***	0.23	
Taiwan Fertilizer Co.	-0.09		0.49	**
Bagfas Bandirma Fabrikalari	0.39		-0.21	
Gübre T.A.S.	0.36		0.26	
Andersons	0.17		0.38	
Compass Minerals Intl.	0.02		0.17	
LSB INDS.	0.59		0.27	
Terra Nitrogen Company	0.84		0.1	
Mosaic Company	0.48		0.66	**
Yara	0.47		0.07	
Uralkali				
Total Average	0.16		0.26	

Note: ***, **, and * denotes significance at the 1%, 5% and 10% level.

Table 2.11
Thirty fertilizer firms' sensitivities to the World Fertilizer Index and the GSCI Ags from Jan 2008 to Dec 2012

Whole Sample	From January 2008 to December 2012			
30 Listed Fertilizer Firms	Fertilizer Index		GSCI Ags	
Rosier S.A.	0.24		0.48	***
Fosfertil (Vale Fertilizantes S.A.)	0.26		0.41	**
Spur Ventures Inc.	0.07		0.8	***
Agrium Inc.	0.2		1.14	***
PotashCorp./Saskatchewan Inc.	0.42	*	0.95	***
SQM	0.28		0.7	***
Abu-Qir Fertilizers & Chemical Ind. Co.	0.25		0.39	**
E.F.I.C.-Egyptian Financial & Industrial Co.	0.64	**	0.59	**
K + S	0.4	*	1	***
Sinofert Holdings Ltd	0.13		0.45	**
Mangalore Chemicals & Fertilizers	-0.24		0.53	***
Nagarjuna Frtz & Chem	0.19		0.63	**
National Fertilizers Ltd	-0.14		0.72	***
Zuari Industries Ltd	0.06		0.82	***
ICL	0.46	**	0.73	***
AB Lifosa	0.52	*	0.57	**
Dawood Hercules Chemicals Ltd	0.05		-0.05	
Fauji Fertilizer Company Ltd	-0.07		0.05	
SAFCO - Saudi Arabian Fertilizer Company	0.47	**	0.44	***
Sesoda Corp.	0.48	*	0.49	**
Taiwan Fertilizer Co.	0.1		0.6	***
Bagfas Bandirma Fabrikalari	0.48	**	0.31	*
Gübre T.A.S.	0.87	***	0.31	
Andersons	0.55	**	0.53	**
Compass Minerals Intl.	0.25		0.37	***
LSB INDS.	-0.16		1.02	***
Terra Nitrogen Company	0.04		0.8	***
Mosaic Company	0.36		1.26	***
Yara	0.37		1.13	***
Uralkali	0.88	***	1.07	***
Total Average	0.26		0.63	
Total Average including Uralkali	0.28		0.64	

Note: ***, **, and * denotes significance at the 1%, 5% and 10% level**.** All firms have data until 2012 except for Fosfertil, Nagarjuna, Zuari, and Lifosa, which end in 2011

Turning to the sensitivities to the Fertilizer Index, we see a wide range of numbers for the period Jan 2004 to Dec 2007 and a general increase in the period from Jan 2008 to Dec 2012 for all listed firms, with the average increasing from 0.16 to 0.26, possibly because of a greater awareness of fertilizer prices by investors. Still, across both time periods, we observe that the mean sensitivity to the Fertilizer Index is consistently lower than the mean sensitivity to the GSCI Ag Index, exhibiting clearly that this famous agricultural index acted more as investment driver than the World Fertilizer Index (see Tables 2.10 and 2.11). Regarding the increased sensitivity to the latter in the second period, a reasonable explanation may reside in a greater awareness of fertilizer prices after the first food crisis.

The German company K+S, which extracts potash and magnesium salts in Germany, and ICL from Israel, which exploits various products based on phosphate rock, continued to do well after 2008 (as illustrated in Section 3). Both present high sensitivities to the GSCI Ag Index. ICL exhibits a higher sensitivity than K+S to the Fertilizer Index in the second period, possibly because it was then (and in 2013) the subject of several acquisition offers.

Different behaviors are also related to geography and specific corporate events. For instance, during the second period, the Lithuanian company AB Lifosa displayed high levels of returns and larger sensitivities to both the Fertilizer Index and the GSCI Ags index. The Brazilian company Fosfertil exhibited increased sensitivity to the GSCI Ags index but not the Fertilizer Index in the second period. Fosfertil (currently Vale Fertilizantes) was acquired by Vale in 2010, which also acquired Bunge's nutrient assets in Brazil (Vale Fosfatados) – Brazil still imports 50% of the fertilizers it consumes.

The location of the firms plays an important role in attracting investment. Our sample contains four Indian companies: Mangalore Chemicals and Fertilizers, Nagarjuna Fertilizers and Chemicals, National Fertilizers Ltd and

Zuari Industries Ltd. In India, fertilizers have been heavily subsidized and retail prices are controlled by the state. For the past three decades, India has had a very aggressive program in the subsidization of fertilizers. As a percentage of total government subsidies, fertilizer subsidies accounted for 47% and food subsidies 35.1% during the 1990s. It is interesting to see that, accordingly, Indian fertilizer companies exhibit fairly low sensitivities to the Fertilizer Index, and high ones to the agricultural index, which appear to be a more important driver of their share prices.

In conclusion, we observe that after 2008 a number of companies located in different regions exhibited the feature of not having been able to maintain the very strong profits achieved in the years 2006 and 2007. Still, the average sensitivities of all firm shares remained the highest to the GSCI Ag Index, i.e., cereals' prices as opposed to fertilizer prices, making these stocks a partial hedge against food-related inflation risk. This property is also important for investment decisions in the agribusiness world.

5. Conclusion

In this Chapter, we take the perspective of capital investment in the fertilizer-mining industry. Sources of new equity for the extraction and processing of phosphate, potash, and nitrogen are crucial in order to increase crop yields for additional food supply in order to satisfy the needs of a growing world population in a context of stable or eroding *arable land* – making fertilizers one of the rare solutions to a problem faced, in particular, by emerging countries. In this order, we describe the main features of fertilizer markets as well as compare movements of fertilizer prices with corn and wheat over the last decade, since individual investors are more aware of corn and wheat prices, which are regularly published in ordinary newspapers and daily news.

We also show that early movers in the purchase of fertilizer-related companies' stocks, when the importance of fertilizers in the world economy first became visible to the investment community, obtained returns as high as 60% over the period January 2004 to December 2007. This so-called 'leverage effect' achieved by commodity equities during a period of upward movement in the underlying commodity price has been discussed by equity analysts in the oil and natural gas industry. The same property has been observed in the share prices of gold-mining companies (Tufano, 1998).

Lastly, we illustrate how pension funds and insurance companies wishing to hedge the inflation risk embedded in variable annuities sold to future retirees should include shares of fertilizer-mining companies in their portfolios since they exhibit significant sensitivities to the prices of agricultural commodities, which are a key component of inflation indexes.

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Chapter 3. Revisiting uncertainty and price forecast indicators in corn and wheat markets

1. Introduction

In contrast to crude oil prices which started rising in 2002, followed by copper, gold and other metals, agricultural commodity prices were essentially flat (declining in fact if adjusted for inflation) until 2006. In the agricultural year 2006-2007, different weather events around the world sent corn and wheat prices to unprecedented levels. As of that moment, food price risk became a large concern for governments and regulators alike.

Our goal in the first part of this chapter is to argue that the famous volatility (i.e., standard deviation of returns) that is widely discussed, analysed, and estimated in the financial markets is not the most informative quantity in the case of commodities. This is especially the case for agricultural commodities, since the absolute prices are what matter most for populations and, hence, also for governments and regulators. We propose to focus on the signals provided by the coefficient of variation and the standard deviation of price as alternative measures of uncertainty, and illustrate their effectiveness in the case of corn and wheat. .

In the second part of the chapter, we look at the predictive power of several models that involve corn and wheat Future contracts. It is usually recognized that Futures markets incorporate information quicker than spot markets due to low transaction costs, liquidity, and the feasibility of long and short positions. Price discovery allows the transfer of price information, from commercial merchants that have more accurate information about planting decisions and future harvests than other players that do not have access to this information. If the number of players on the buy and sell sides with full information was large enough, the expectation of Futures prices should, in principle, be an unbiased prediction of spot prices. We compare the quality of future price prediction provided by individual forward contracts versus the geometric average of the forward curve introduced in Borovkova and Geman (2006). We show that the latter performs better for corn and wheat spot prices.

Our findings in the first and second parts of the paper are intrinsically related because they provide important information for participants in the market, including farmers, consumers, and government regulators, and policymakers. Since our investigation is directly linked to the realities of the physical markets themselves, we also provide the reader with the essential background needed to understand the corn and wheat markets. Explanations of the physical commodities are vital in order to be able to see how Futures prices are capturing the market.

The chapter is organized as follows. Section 2 presents some fundamentals of corn and wheat. Section 3 describes several measures of dispersion and their implications for the security of food price. Section 4 analyses the validity of individual Futures contracts and $\bar{F}$, the geometric average of the forward curve in terms of predicting future spot prices. Section 5 concludes.

2. Fundamentals of Corn and Wheat Markets

2.1. Corn

As a feed, corn is the highest valued among the cereal grains for its energy content, consisting of 65 per cent starch, 4 per cent oil and 10 per cent fibre. In temperate climates, corn must be planted in the spring. It is a more water efficient crop than soybeans or alfalfa but requires a larger amount of fertilizers. A corn crop producing six to nine tonnes of grains per hectare requires 31 to 50 kg of phosphate fertilizer while a soybean crop requires 20 to 25 kg per hectare (Geman and Vergel Eleuterio, 2013).

The United States is the biggest producer of corn in the world, and corn production accounts for over 95 per cent of total feed grains production (of the other feed grains, sorghum accounts for 2.9, barley for 1.5 and oats for 0.5 per cent). The next largest corn producers are China, Brazil, and the EU-27. Main world exporters are the United States, Argentina, Brazil, and Ukraine. The biggest importers are Japan, South Korea, the European Union and Mexico. Depending on the government policy and climate conditions, China alternates between years of high exports and high imports, thus making it a source of uncertainty for the world corn market.

The Chicago Mercantile Exchange (CME) offers a wide variety of financial derivatives written on corn including corn Futures, a mini-corn Futures contract, calendar swaps, and a wide variety of options contracts, including new crop options.

2.2. Wheat

A fundamental staple of the human diet, wheat comprises approximately twenty per cent of calories and proteins consumed on a global scale. Worldwide, approximately ten per cent of wheat grain production is used annually for feed. A high starch content of roughly seventy per cent dry matter makes this cereal grain rich in carbohydrates. In addition to having a greater amount of protein (hard and durum wheat have more proteins than soft wheat) than corn or barley, wheat protein is also of a higher calibre, making the grain a valued substitute for corn. It is important to note, however, that the content and quality of crude protein and starch can vary with growing conditions, wheat species, fertilizers, and other factors.

Common (or bread) wheat grain is primarily processed into flour for bread, pastry, and the confectionary industry. The production of bread and similar products is aided by gluten, a protein unique to wheat, which helps dough to rise. Gluten is commonly used to thicken foodstuffs including soup, gravy, and sauces. Durum wheat, which is lower in gluten content, is used in the production of pastas, semolina, couscous, pizza bases, and other flat breads.

The main producers of wheat are the EU-27, China, India, and the US. Major exporters are the US, EU-27, and Australia and the largest importers include Egypt, Brazil, Indonesia, Japan, Algeria, the EU-27 and South Korea. Wheat Futures, including a mini-wheat Futures contract, calendar swaps and options contracts as well as Black Sea Wheat Futures, Kansas City Wheat Futures (KC Wheat), options and swaps from the Kansas City Board of trade (KCBT) can be purchased through the CME. Other products include Minneapolis Grain Exchange - Chicago Board of Trade Wheat Spread options (commonly known as MGEX-CBOT Wheat Spread Options) as well as Futures and short-dated new crop options.

2.3. Links between corn and wheat

In *Crops and Man* (1975), renowned botanist Jack Harlan stated the following: “Fully domesticated plants are artefacts produced by man as much as an arrowhead, a clay pot, or a stone axe.” This is certainly true of most, if not all, agricultural commodities currently traded and consumed on a global scale. Centuries of research and careful breeding (for example, to create hybrids) together with the development of fertilizers, pesticides, and herbicides have resulted in better quality crops, higher yields, and greater resistance to pests and adverse weather conditions.

Corn and wheat are two central agricultural commodities which have benefited from such developments. With incomes rising in developing countries such as China and India, there has been a shift from basics such as rice and wheat to more expensive foodstuffs including meat, dairy, and vegetable oils. The increase in demand for meat and dairy requires the expansion of the meat production industry which, in turn, requires more feed grains. Although the rate of population growth has slowed significantly with the decline in birth rates, demographers still forecast a rise to ten billion just after 2050. Providing nourishment for everyone will require at least 35 per cent more calories than what is currently produced today. Taking into account the continual increase in meat consumption, the percentage of grains needed is much greater. Animal nutrition, which is ultimately dependent on agricultural commodities, will be crucial in meeting objectives for meat production.

Both corn and wheat are used for animal feed. Corn and its by-products are valued for their high energy content but have low protein content and need to be supplemented in order to provide the appropriate amount of proteins and amino acids. For this reason, corn is traditionally mixed with soybean meal when used as an animal feed. Wheat that is not fit for human consumption or food processing is used for animal feed. With a higher amount of protein, minerals, oil and fibre than wheat grain, wheat bran – a by-product of the dry milling process used to make flour and produce pasta from durum wheat – is also a major animal feed. The link of corn, wheat and soybeans is apparent in the offering of financial products. The CME offers a wide variety of cross commodity financial products such as Wheat-Corn spread options and Soybean-Corn price ratio options.

Wheat and corn also share important connections through crop rotation, double cropping, and intercropping. It has long been shown that crop rotation – a planting method involving the growth of various crops in a strategic, sequential order – of corn, soybean, and wheat in a three year rotation results in improved soil quality, reduced risk of pests and pathogens, better weed control and most importantly, sustained yields. A study by Michigan State University (Lipps et al. 2001) reports that including wheat in the rotation is vital for increasing yields of other crops like corn and soybeans by at least ten per cent. In addition, crop rotation can be beneficial in reducing risks associated with poor weather conditions; for example, during the drought of 2012, wheat yields were above average while corn was adversely affected. Double-cropping, when a second crop is planted after harvesting the first, is also common in the cases of corn, wheat and soybeans. In the US, it is usual to find double-cropping, for example, with corn and alfalfa rotating in colder areas or corn and soybeans in areas with longer summers. A third crop, such as winter wheat, can also be added to the rotation. In “relay intercropping”, two crops are planted in the same field; for example, soybeans can be planted on a field where wheat is currently growing.

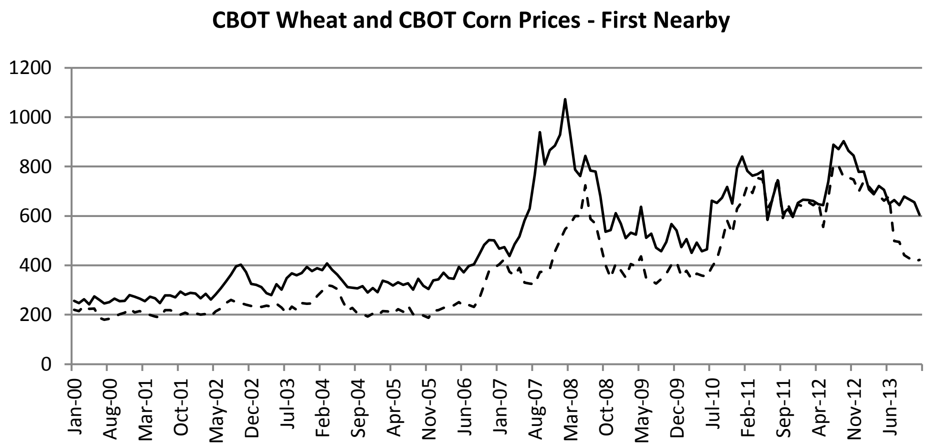


Figure 3.1. First nearby prices of CBOT Wheat (solid line) and CBOT Corn (dash line) in US cents per Bushel

Since the start of 2004, a dramatic increase has prevailed in the open interest of CBOT Corn and CBOT Wheat Futures contracts. The biggest rise in open interest was for CBOT Wheat, which increased from around 100,000 contracts in 2005 to a high of 550,000 in 2006. Corn followed and by spring 2006, banks accounted for twenty per cent of the total open interest for wheat and twelve per cent for corn. Additionally, from mid-2007 to mid-2008, we observe a widening of the spread between wheat and corn prices. This coincided with a period of increased prices due to tight wheat supplies, record wheat prices, human consumption demand being inelastic to prices, and a large amount of trading carried out by index funds. Historically, CBOT Wheat and CBOT Corn have moved together, with the price of wheat typically one to two dollars higher than corn. Only on very rare occasions does this spread invert. However, corn prices reached a record high in April 2011 and surpassed the price of wheat due to a growing demand for corn-based ethanol and tight level of supplies not seen since the 1930s (see Figure 3.1).

3. Volatility, Coefficient of Variation and Standard Deviation of Prices of Corn and Wheat

Traditionally, finance literature has concentrated on the use of returns rather than prices, and volatility rather than standard deviation of prices as a measure of variation. This began with the Portfolio Theory of Markowitz (1958), where the naturally important quantities to analyze are returns on stocks, whatever the initial wealth owned by the investor. It continued with the Black-Scholes-Merton (1973) model, in which the mathematical assumption on the underlying stock price was expressed through the stochastic dynamics of its returns.

Geman and Ott (2013), in a report to the EU Commission, argue that volatility, defined as the standard deviation of returns traditionally used in finance, is not the best measure of uncertainty in the case of agricultural commodities, since absolute prices are what matter for populations, and hence also for governments and regulators. We investigate this point by considering two alternative measures of uncertainty, namely the coefficient of variation (CV) and the standard deviation of prices in the case of corn and wheat and show that the CV and standard deviation of prices would have provided better warning signals with regards to rising food prices, and the related crises since 2006 in countries such as Tunisia and Egypt.

The monthly volatility of returns – with returns classically approximated by log differences - is computed from monthly data as follows:

$$Volatility = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(\Delta \ln p_i - \frac{1}{n}\sum_{i=1}^{n}\Delta \ln p_i\right)^2} \qquad (1)$$

where p_i is the dollar value of the CBOT closing price of the commodity nearby Future contract on month *i* and *n* is the number of monthly observations. It is annualized by multiplying the monthly volatility, as calculated above, by $\sqrt{12}$. We calculate the annualized volatility in a similar way when using daily or weekly data, by multiplying volatility by $\sqrt{250}$ or $\sqrt{52}$, respectively .

From an econometric point of view, the use of returns makes sense since the return series is more likely to be stationary, which allows the use of a wide range of econometric tools. This reasoning is not optimal, however, for agricultural commodities. The repeated crises since 2006 have brought the focus on the right entity of concern, namely the price prevailing in the world market. Price levels are reflected in the cost of food and food security for poorer individuals who have no interest in returns, and in turn for policymakers.

Hence, an investigation of the different measures of dispersion of prices (and not just returns) is, in our view, hard to avoid when dealing with food commodities. Different types of participants may benefit from distinct measures of dispersion. For instance, since farmers are directly affected by price volatility, which can have a long term influence on producers and their production schedule, they should be most concerned with the standard deviation of prices. This measure best captures intra-year volatility of the price level driven by low stock to use ratio, or tight supply. In contrast, investors care about the return of the asset and the risk attached, which is best measured by the volatility of returns. Government regulators and policymakers would benefit from using the coefficient of variation since it gives better intra-year information (for example, in 2004 when there was a dramatic increase in the open interest of corn and wheat Futures contracts); this measure could allow them to confront changing conditions more quickly. For example, in a study analysing the volatility of eight commodities, it is the CV that exposes sharp increases in volatility (Huchet-Bourdon, 2011).

The coefficient of variation lies somewhat in the middle of volatility and standard deviation of prices. Like volatility, it is independent of units of measurement; however, its computation bears directly on prices. The annualised coefficient of variation, CV, is usually defined as the ratio of standard deviation σ and the mean μ of the price series

$$CV = \frac{\sigma}{\mu} \qquad (2)$$

It is customary to use the sample standard deviation and the sample mean when calculating the coefficient of variation. In the continuity of our analysis above, we use monthly prices and annualize in the same way.

The standard deviation of prices, unlike returns or the coefficient of variation, keeps the original units of measure. We recall that the standard deviation of the sample of size *n* is computed as:

$$Standard\ deviation = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(p_i - \frac{1}{n}\sum_{i=1}^{n} p_i\right)^2} \quad (3)$$

To analyze the measures of dispersion for corn and wheat using formulas (1), (2), and (3), we use monthly data from January 2000 to December 2013. The first nearby, F1, is used as a proxy for the spot price, S_t, throughout the chapter. The contracts chosen for each commodity are their respective world benchmarks: in the case of wheat, we use Future contracts on No. 2 Soft Red Winter Wheat and for corn, the No. 2 Yellow Corn Future contract, both traded on the CME Futures US Exchange. In all cases, we respect the 'last trading day' rule for consistency.

3.1. Corn

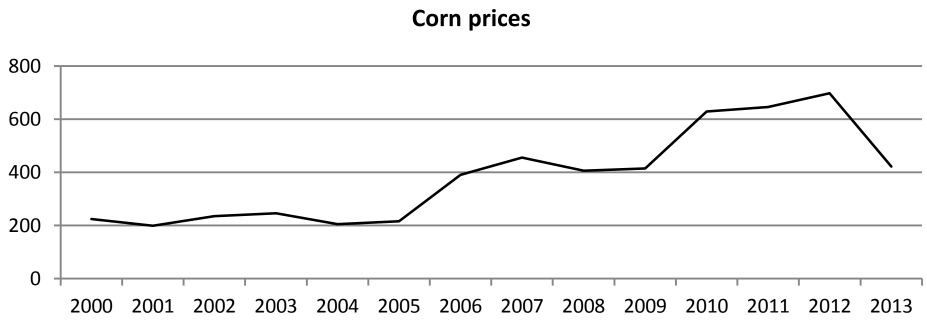
From Figures 3.2 and 3.3, with results depicted in Table 3.1, we obtain a clearer picture of the pros and cons of each measure. Starting with volatility, we observe values around 20 per cent until 2003, increasing to around 30 per cent from 2004 to 2007, with a peak of 47 per cent in 2008 and values well over 30 per cent afterwards.

Table 3.1
CBOT Corn: annual returns, annualized monthly volatility, coefficient of variation, standard deviation of prices, and annual closing prices from 2000 to 2013

Years	2000	2001	2002	2003	2004	2005	2006
Annual Returns	0.09	-0.12	0.16	0.04	-0.18	0.05	0.59
Volatility	0.26	0.20	0.17	0.24	0.33	0.30	0.27
CV	0.31	0.16	0.35	0.18	0.67	0.22	0.77
SD	64.58	33.37	79.32	41.52	169.21	45.32	206.35
Price	224.75	199.75	235.25	246	204.75	215.75	390.25

Years	2007	2008	2009	2010	2011	2012	2013
Annual Returns	0.15	-0.11	0.02	0.42	0.03	0.08	-0.50
Volatility	0.34	0.47	0.35	0.37	0.40	0.35	0.32
CV	0.37	0.69	0.32	0.79	0.30	0.37	0.80
SD	138.28	363.16	121.08	343.86	201.34	261.15	459.23
Price	455.5	407	414.5	629	646.5	698.25	422

The coefficient of variation also shows low values up to 2003, and then starts exhibiting a spiky behavior. Turning to the standard deviation of prices, we observe values lower than 100 in the years 2000-2003, followed by much higher values, which should have been a striking signal for regulators and policy makers.



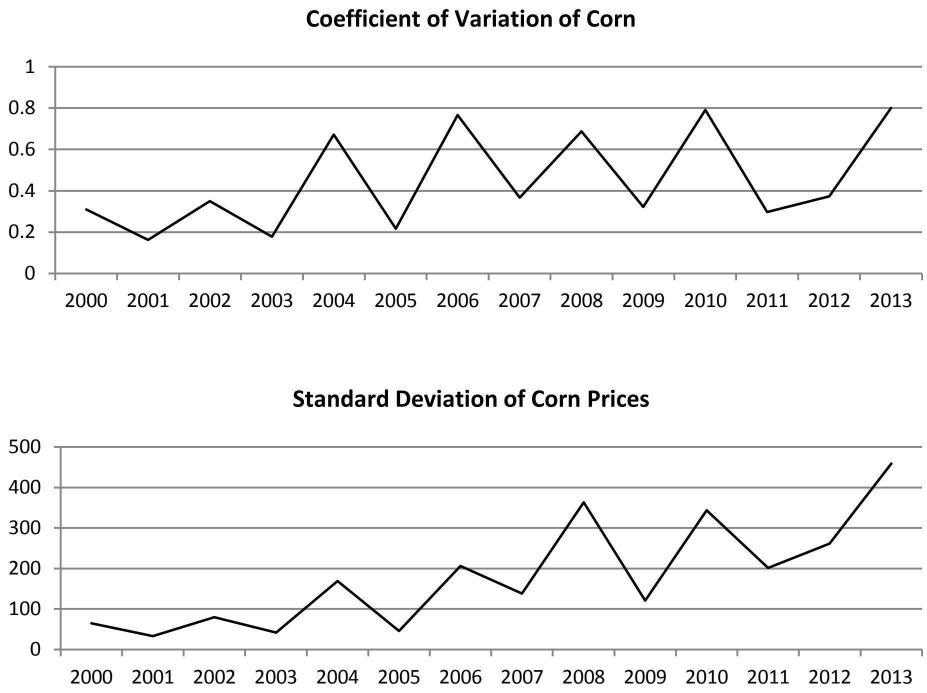
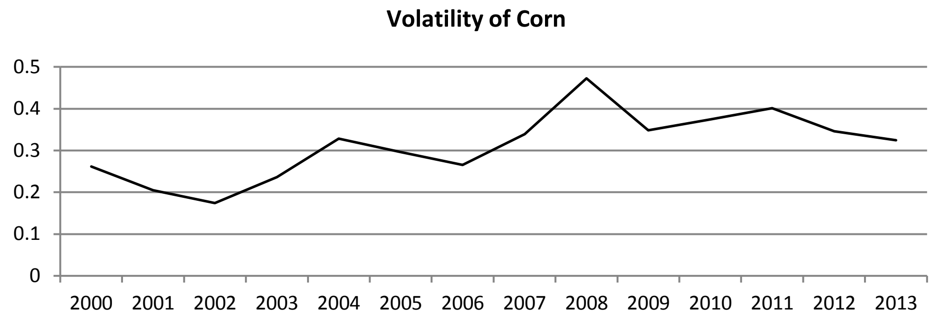


Figure 3.2. CBOT Corn: closing price, coefficient of variation, and standard deviation of prices per year from 2000 to 2013

The year 2004 was an exceptional year for corn. There were remarkably low levels of stock carried from 2003 and the 2004 harvest was the largest one on record. The effects of both scarcity and abundance of grains that year are easily observable in the price movements. Corn prices reached a maximum of 316.5 cents per bushel in April and went down to 192.5 by November, partially recovering by the end of the year. This intra-year variation is particularly well reflected in the coefficient of variation and the standard deviation of prices, making the case for focusing attention on these two values, as opposed to volatility. Regulators should have read the warnings in these numbers, which signalled the bigger crises to come.



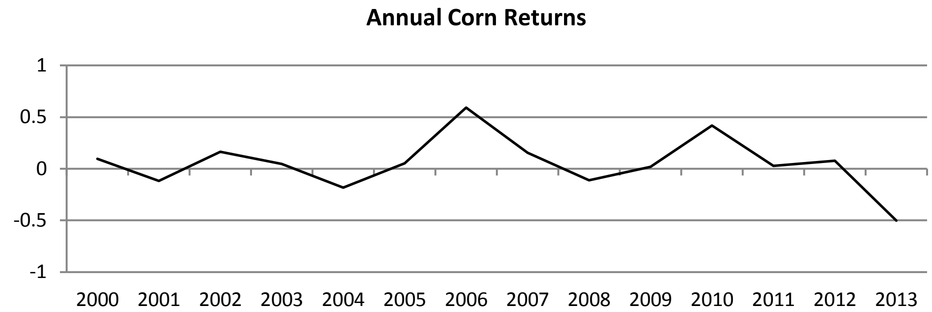


Figure 3.3. CBOT Corn: annualized monthly volatility and annual returns from 2000 to 2013

3.2. Wheat

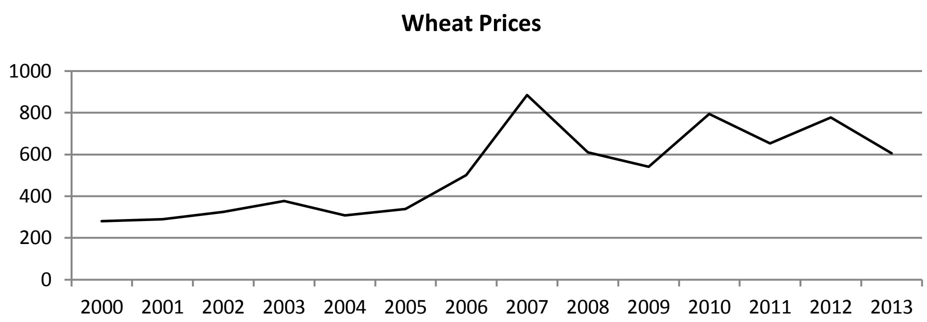
In the case of CBOT Wheat, we also observe how the alternative measures of dispersion give different views on what has occurred in recent years. While volatility presents a clear upward trend from 2006 before declining in 2011, both the annualised coefficient of variation and standard deviation of prices show a decline much earlier (See Table 3.2 and Figures 3.4 and 3.5).

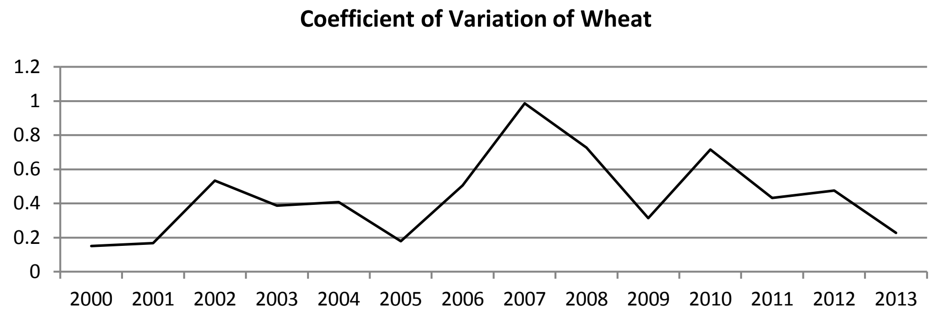
Table 3.2
CBOT Wheat: annual returns, annualized monthly volatility, coefficient of variation, standard deviation of prices, and annual closing prices from 2000 to 2013

Years	2000	2001	2002	2003	2004	2005	2006
Annual Returns	0.12	0.03	0.12	0.15	-0.20	0.10	0.39

Volatility	0.22	0.20	0.28	0.27	0.19	0.29	0.21
CV	0.15	0.17	0.53	0.39	0.41	0.18	0.51
SD	38.93	45.64	173	130.64	139.27	57.90	206.43
Price	279.5	289	325	377	307.5	339.25	501

Years	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Annual Returns	0.57	-0.37	-0.12	0.38	-0.20	0.18	-0.25
Volatility	0.37	0.43	0.40	0.49	0.44	0.26	0.17
CV	0.99	0.73	0.31	0.72	0.43	0.48	0.23
SD	646.39	560.92	165.98	417.44	303.96	364.05	155.21
Price	885	610.75	541.5	794.25	652.75	778	605.25





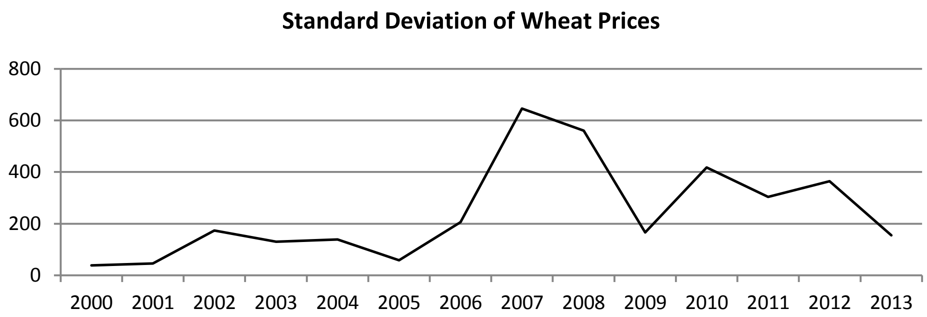
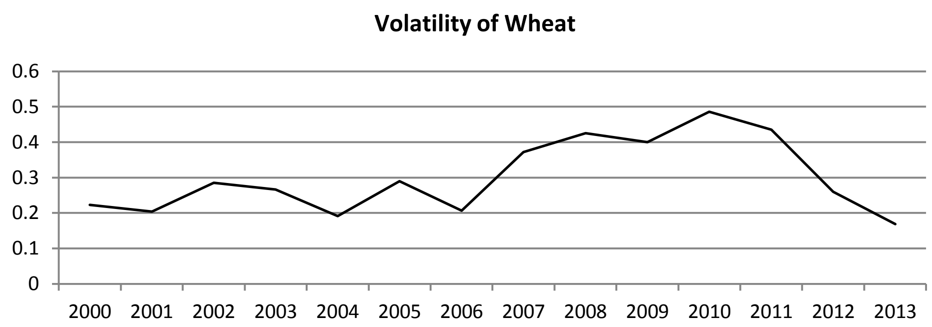


Figure 3.4. CBOT Wheat: closing price, coefficient of variation, and standard deviation of prices per year from 2000 to 2013



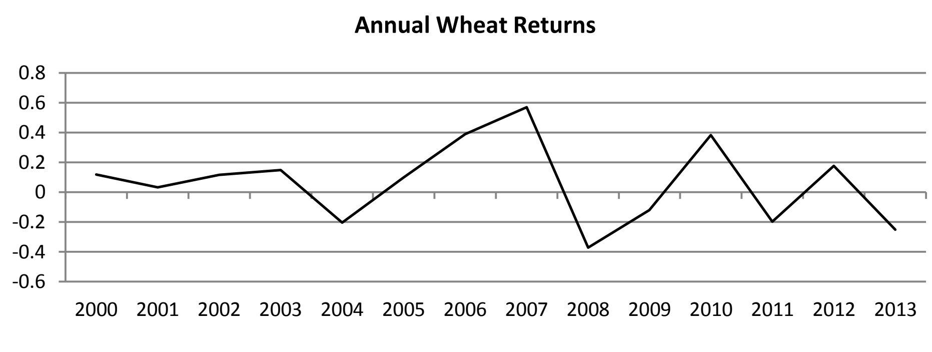


Figure 3.5. CBOT Wheat: annualized monthly volatility and annual returns from 2000 to 2013

In conclusion, for both corn and wheat, the increase in the coefficient of variation and standard deviation of prices was much more dramatic than volatility from mid-2005, and therefore could have been a warning signal for governments and regulators for the subsequent food crises which especially threatened the food security of poorer countries. The coefficient of variation and the standard deviation of prices provide different information, since the first is given in percentage terms and the latter in the original unit of measurement. As previously mentioned, different measures will benefit different entities.

4. Examination of Alternative Predictors of Spot Prices

In this section, we turn our attention to the information contained in Futures prices. There is a long history of price expectations models, beginning with Hicks' publications "Value and Capital" (1939, 1946) and "Capital and Growth" (1965). It was Muth (1961) who developed the econometric version of the Rational Expectations Hypothesis (REH). Following his work, numerous studies have been conducted to test the unbiasedness of the forward exchange rate as a predictor of the spot exchange rate in the future - See, for example, Cornell (1977), Geweke and Feige (1979), Hansen and Hodrick (1980), Longworth (1981), and Frenkel (1981). There also exist empirical studies for commodities, including those of Goss (1983), and Pieroni and Ricciarelli (2005). There has been much debate in the literature as to whether or not Futures prices are valid predictors of future spot prices, with numerous empirical studies finding evidence of an efficient market and many providing evidence to the contrary. A classic paper by Fama and French (1987) studies the forecast performance of

21 commodities Futures contracts and find that ten have predictive power. A study by Bopp and Lady (1991) find that, depending on market conditions, either the Futures price or spot price for crude oil has greater predictive ability, thus providing evidence against the REH. The results of Chinn et al. (2005) are mixed; they find forecasting evidence in the petroleum, gasoline, and heating oil markets, but not for natural gas over the period 1999 to 2004. Reeve and Vigfusson (2011) show that, in the case of crude oil, when the Futures price is five percent or more above spot prices, the predictive ability of Futures prices increases substantially. In general, across several commodities, their results suggest that Futures prices give more information about the future spot price as the two prices grow farther apart in time. Results from Yang et al. (2001) support the REH; they find evidence that Futures prices for many agricultural commodities including corn, wheat, and soybeans are unbiased predictors of future spot prices in the period from 1996 to 1998. However, in recent years, the agricultural commodities markets have greatly changed and, in our opinion, a re-examination of forward curve prediction is highly relevant, not just in the REH framework but also in terms of the predictive power of Futures contracts at several lags.

Lucas (1972) extended the REH to macroeconomics and was awarded a Nobel Prize for his work. According to his perspective, the REH is a conjecture that can be the core of an empirically testable price expectations model. The REH implies that the forward price at date t for maturity date $t+h$, F_t, should be an unbiased predictor of the commodity spot price at $t+h$:

$$f(t, t+h) = E_p(S(t+h)/I_t) + u_{t+h} \tag{4}$$

where I_t is the filtration incorporating all information until date t, and u is an error term with conditional expected value of zero and uncorrelated with the information at time *t*. By adding the no-arbitrage assumption and changing the probability measure, the above relationship can be written as an exact equality.

4.1 Individual forward contracts as predictors of future spot prices

In order to test the relationship between spot and forward prices, we use log prices of Futures daily data for corn and wheat; price observations with zero volume are removed in advance. The contracts chosen for each commodity are regarded as their respective world benchmarks. In the case of wheat, we use Future contracts on No. 2 Soft Red Winter Wheat and for corn, the No. 2 Yellow Corn Future contract. Both contracts have delivery months in March, May, July, September and December and are traded on the CME Futures U.S. Exchange (see examples of forward curves in Figure 3.6) and their last trade date is the last business day prior to the 15th calendar day of the contract month. For simplicity, no adjustments for the rollover of contracts have been made.

Under constant interest rates or absence of correlation of these to the underlying asset, arguably the case for agricultural commodities, forward and Future prices are equal. The first test involves running the regression:

$$\ln S_t = \alpha + \beta \ln f_{t-h} + \varepsilon \qquad (5)$$

with *h* expressed in number of months. In this analysis, we are interested in the results of the F-tests (null hypothesis: α=0 and β=1) on the intercept of the regression and the slope of the lagged forward price.

The main drawback of this test is that it could be allocating a predictive power to the forward price that could also be attributed to the lagged spot price.

Hence, a second F- test (null hypothesis: α=0 and ρ =1) is used based on the regression:

$$\ln S_t - \ln S_{t-h} = \alpha + \rho \quad (\ln f_{t-h} - \ln S_{t-h}) + \varepsilon \qquad (6)$$

In this test, the change in the spot price, $\ln S_t - \ln S_{t-h}$, is explained by $\ln f_{t-h} - \ln S_{t-h}$, a quantity that defines the magnitude of backwardation or contango at date *t-h*. This test deals with log differences, which are generally stationary, and subtracts the effect of the lagged spot price from both sides of the equation. When ρ = 1, the regression represented by equation (6) reduces to that of equation (5) when β = 1.

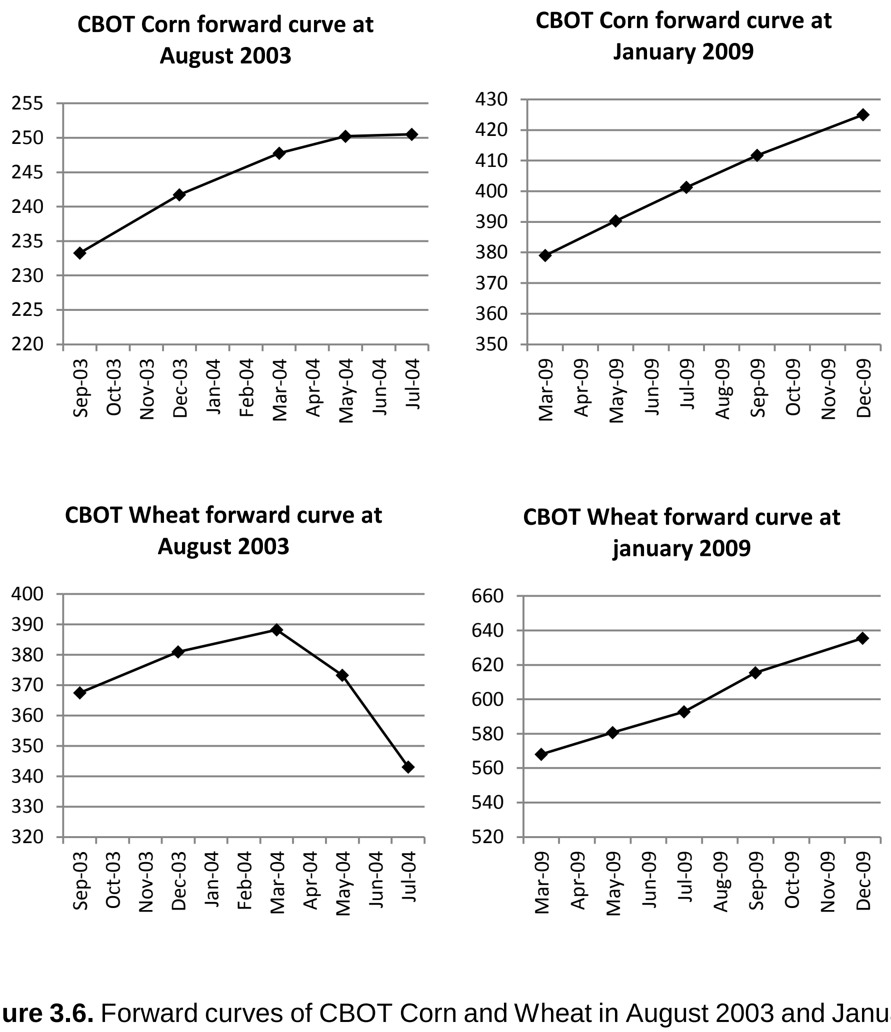


Figure 3.6. Forward curves of CBOT Corn and Wheat in August 2003 and January 2009

We pose two questions. First, do forward prices before the US corn planting period predict spot prices after the harvest? Second, will these estimates be affected by the proximity of the observed forward prices to the contract expiry date? In order to answer these questions, we test the predictive power of each maturity with its corresponding spot price, i.e., we compare how the July Future price observed at time *t-h* predict July spot prices, the September Future prices predict September spot prices, etc.

First, we place ourselves at two particular points in time: the beginning of February and the beginning of April (30 days before the maturity of the Future contract). These are the dates when observations of the forward curve are taken, in Tables 3.3a and 3.3b, for a length of 10 business days. The corn heading (stage of development of grains where the head pushes its way through the flag leaf sheath) and harvesting happen during the summer months. The farmer will be interested in inferring information about post-harvest prices after the harvest, i.e., after September, from the forward curve. Accordingly, the October corn option contract is the most traded.

Tables 3.3a and 3.3b
F-test results for equations (5) and (6) for CBOT Corn, with forward curves observed approximately from February 1st to 14th and April 1st to 14th, respectively, 30 days before expiry.

Approx. date:		**1-14 February**			
Maturities	**Distance to Spot (in months)**	**Equation (5)**		**Equation (6)**	
		F-test	**p-value**	**F-test**	**p-value**
May	2	0.38	0.69	0.10	0.91
Jul	4	4.18	0.02	0.97	0.38
Sep	6	15.54	<0.01	11.03	<0.01
Dec	9	1.84	0.16	3.99	0.02
Mar	12	0.76	0.47	0.24	0.79

Approx. date:		**1-14 April**	
Maturities	**Distance to Spot**	**Equation (5)**	**Equation (6)**

	(in months)	F-test	p-value	F-test	p-value
Jul	2	9.12	<0.01	4.56	0.01
Sep	4	11.91	<0.01	17.72	<0.01
Dec	7	3.72	0.03	3.42	0.04
Mar	10	0.45	0.64	0.33	0.72
May	12	0.43	0.65	0.40	0.67

Note: The null hypothesis for Equation (5) is: $\alpha=0$ and $\beta=1$. The null hypothesis for Equation (6) is: $\alpha=0$ and $\rho=1$. For the period 1-14 of February (Table 3.3a), we reject the null at the 5% level for July and September Maturities in the case of Equation (5) and September and December in the case of Equation (6). At the beginning of April (Table 3.3b), we reject the null at the 5% level for the first three maturities, in case of both Equation (5) and Equation (6).

From Tables 3.3a and 3.3b, we clearly see that forward prices observed at the beginning of February produce better estimates of corn spot prices than the ones observed in the beginning of April, when planting is already underway (most planting is done in the US from April to May). Although the March Futures contract maturing the following year offers unbiased predictions of future March spot prices in both cases, the earliest contract that provides some post-harvest information is the December Futures contract (see Table 3.3a).

We detect an important effect on the predictive power of the forward prices as the contracts get closer to expiry. When we compare results from Tables 3.3a and 3.3b with the results from Tables 3.4a and 3.4b, where we observe the forward curve during the last ten trading days before maturity of the contract, the predictive power of the forward prices, in general, is greatly reduced. Hence, in any study with daily observations, the last 10 trading days before maturity should not be taken into consideration; the same applies to observations with no liquidity.

Tables 3.4a and 3.4b

F-test results for equations (5) and (6) for CBOT Corn, with forward curves observed approximately from March 1st to 14th and May 1st to 14th, respectively, 10 days before expiry.

Approx. date:		1-14 March			
Maturities	Distance to Spot (in months)	Equation (5)		Equation (6)	
		F-test	p-value	F-test	p-value
May	2	3.71	0.03	3.52	0.03
Jul	4	16.26	<0.01	12.14	<0.01
Sep	6	13.90	<0.01	10.07	<0.01
Dec	9	4.31	0.02	4.75	0.01
Mar	12	0.65	0.52	0.66	0.52

Approx. date:		1-14 May			
Maturities	Distance to Spot (in months)	Equation (5)		Equation (6)	
		F-test	p-value	F-test	p-value
Jul	2	5.37	<0.01	10.44	<0.01
Sep	4	4.13	0.02	10.51	<0.01
Dec	7	6.34	<0.01	3.22	0.04
Mar	10	1.00	0.37	0.69	0.50
May	12	0.21	0.81	0.10	0.90

Note: The null hypothesis for Equation (5) is: $\alpha=0$ and $\beta=1$. The null hypothesis for Equation (6) is: $\alpha=0$ and $\rho=1$. For the period 1-14 of March (Table 3.4a), we reject the null at the 5% level for the first four Maturities – May, July, September, and December - in the case of both

Equation (5) and Equation (6). At the beginning of May (Table 3.4b), we reject the null at the 5% level for the first three maturities, for both Equations (5) and (6).

Similar questions can be asked for wheat, although the case of wheat is markedly different. First, as we did in the case of corn, we compare the results derived from forward curves observed at the beginning of February to those observed at the beginning of April (see Tables 3.5a and 3.5b). At the beginning of February we only obtain unbiased estimates of spot prices from the September Futures contract (the month of March is important because it is a weather/moisture critical period in the heading of wheat in the southern hemisphere), whereas at the beginning of April, we obtain unbiased estimates from all maturities.

Tables 3.5a and 3.5b
F-test results for equations (5) and (6) for CBOT Wheat, with forward curves observed approximately from February 1^{st} to 14^{th} and April 1^{st} to 14^{th}, respectively, 30 days before expiry.

Approx. date:		**1-14 February**			
Maturities	**Distance to Spot (in months)**	**Equation (5)**		**Equation (6)**	
		F-test	**p-value**	**F-test**	**p-value**
May	2	93.74	<0.01	67.17	<0.01
Jul	4	38.70	<0.01	19.80	<0.01
Sep	6	4.00	0.02	0.67	0.52
Dec	9	17.64	<0.01	11.67	<0.01
Mar	12	7.65	<0.01	7.96	<0.01

Approx. date:		**1-14 April**			
Maturities	**Distance to Spot (in months)**	**Equation (5)**		**Equation (6)**	
		F-test	**p-value**	**F-test**	**p-value**
Jul	2	9.26	<0.01	1.18	0.31
Sep	4	2.72	0.07	1.76	0.18
Dec	7	15.13	<0.01	1.58	0.21
Mar	10	7.34	<0.01	1.96	0.14
May	12	11.91	<0.01	1.29	0.28

Note: The null hypothesis for Equation (5) is: $\alpha=0$ and $\beta=1$. The null hypothesis for Equation (6) is: $\alpha=0$ and $\rho=1$. At the beginning of February (Table 3.5a), we reject the null at the 5%

level for all five Maturities in the case Equation (5) and for all Maturities with the exception of September for Equation (6). At the beginning of April (Table 3.5b), we reject the null at the 1% level for all Maturities except for September, in which case the null is rejected at the 10% level, for Equation (5). The null hypothesis cannot be rejected for any Maturity in the case of Equation (6).

When we turn our attention to the issue of closeness-to-expiry effects in wheat, our findings are in line with Reeve and Vigfusson (2011) who find that Futures prices give more information about the future spot price as the two prices grow farther apart in time. We note that the predictive power of many of the maturities is greatly reduced (see Tables 3.6a and 3.6b). As with corn, short term maturities have little predictive power for future spot prices.

Tables 3.6a and 3.6b
F-test results for equations (5) and (6) for CBOT Wheat, with forward curves observed approximately from March 1st to 14th and May 1st to 14th, respectively, 10 days before expiry.

Approx. date:		**1-14 March**			
Maturities	**Distance to Spot (in months)**	**Equation (5)**		**Equation (6)**	
		F-test	**p-value**	**F-test**	**p-value**
May	2	38.52	<0.01	15.22	<0.01
Jul	4	13.26	<0.01	5.03	<0.01
Sep	6	6.21	<0.01	0.40	0.67
Dec	9	16.78	<0.01	6.44	<0.01
Mar	12	12.37	<0.01	4.05	0.02

Approx. date:		**1-14 May**			
Maturities	**Distance to Spot (in months)**	**Equation (5)**		**Equation (6)**	
		F-test	**p-value**	**F-test**	**p-value**
Jul	2	0.51	0.60	13.84	<0.01
Sep	4	3.13	0.05	6.07	<0.01
Dec	7	7.72	<0.01	1.37	0.26
Mar	10	5.46	<0.01	3.23	0.04
May	12	10.38	<0.01	4.28	0.02

Note: The null hypothesis for Equation (5) is α=0 and β=1. The null hypothesis for Equation (6) is α=0 and ρ =1. At the beginning of March (Table 3.6a), we reject the null at the 1% level for all five Maturities in the case Equation (5) and for all Maturities with the exception of September at the 5% level for Equation (6). In the period 1-14 May (Table 3.6b), we reject the null at the 1% level for all December, March, and May and at the 5% level for September in the case of Equation (5). The null hypothesis can be rejected at the 1% level for July and September Maturities and at the 5% level for March and May in the case of Equation (6).

In conclusion, the predictive power of individual forward contracts seems to be most negatively impacted at times of planting, heading and harvesting, and in the days when Future contracts are close to expiry.

4.2 Cointegration and the error correction model

In the previous section, we use the classical framework for testing the REH. Although this framework is still useful for providing inference about the behaviour of Future prices, in recent years, the cointegration and error correction framework has been used in the academic literature to test for the predictive power of forward and Futures contracts on future spot prices. If two I(1) series - non-stationary variables that become stationary after first differencing - are cointegrated, then an important consequence is the Granger representation theorem, which states that the data can be represented by an error correction model. While cointegration tests for a long run relationship, error correction models represent short term variations in this equilibrium relationship between two price series. In their study of futures prices as predictors of spot prices in the crude oil market, Param and Moosa (1999) test for cointegration using the Johansen method as a prerequisite for using an error correction model to represent the data. Krehbiel and Adkins (1993) use the cointegration methodology to test for unbiasedness in four metals markets. Before fitting our data to an error correction model, we divide our data into two subperiods. The data in the first subperiod (in-sample) are used to fit the VECM and the second subperiod (out-of-sample), which consists of the last year of our dataset, is used to evaluate the forecast performance of our models with evaluation metrics including the mean absolute error (MAE), root mean squared error (RMSE), and Theil's inequality coefficient (U).

A study of forward prices, not by maturity but by their position inside the current forward curve, may better represent traders' daily activities. In order to build consistent monthly data series, from the year 2000 to 2014, we use the individual maturities to create continuous series of deliveries, based on how close they are to the spot price. We refer to them as second nearby Future contracts, i.e., F2, third nearby F3, etc. We use the last day of the month and, since the last trading day for each maturity is more than 10 days away, no adjustments in this regard are necessary.

Table 3.7
Descriptive Statistics for corn nearby Future contracts, F1 to F17.

CORN	F1	F2	F3	F4	F5	F6	F7	F8	F9
Mean	5.80	5.81	5.82	5.83	5.83	5.84	5.84	5.85	5.85
Median	5.73	5.74	5.75	5.75	5.74	5.74	5.74	5.73	5.73
Maximum	6.70	6.70	6.70	6.70	6.70	6.70	6.70	6.69	6.69
Minimum	5.18	5.20	5.21	5.23	5.24	5.25	5.25	5.26	5.27
Std. Dev.	0.47	0.46	0.46	0.45	0.44	0.43	0.43	0.42	0.41
Skewness	0.45	0.45	0.44	0.44	0.43	0.43	0.42	0.41	0.40
Kurtosis	1.75	1.74	1.73	1.72	1.72	1.72	1.71	1.71	1.71
Jarque-Bera	15.91	15.98	16.00	15.99	15.93	15.82	15.71	15.52	15.39

CORN	F10	F11	F12	F13	F14	F15	F16	F17
Mean	5.86	5.86	5.87	5.87	5.87	5.87	5.87	5.88
Median	5.73	5.74	5.74	5.74	5.75	5.75	5.73	5.73
Maximum	6.70	6.70	6.70	6.70	6.67	6.63	6.60	6.56
Minimum	5.28	5.30	5.32	5.34	5.36	5.37	5.38	5.39
Std. Dev.	0.41	0.40	0.39	0.39	0.38	0.38	0.38	0.37
Skewness	0.39	0.38	0.37	0.36	0.34	0.32	0.31	0.31
Kurtosis	1.70	1.69	1.65	1.61	1.57	1.54	1.51	1.49
Jarque-Bera	15.37	15.43	15.76	16.24	16.67	17.06	17.52	17.87

Note: All Jarque-Bera statistics are significant at the 1% level, meaning we cannot accept the null hypothesis of zero skewness and excess kurtosis, i.e. the sample is not from a normal distribution.

We interpolate the data between the nearby contracts to the last maturity available to have Future contracts that are equally spaced in time. Due to the fact that in several contracts the time between the current date and the nearby is over one month, we also extrapolate the data so the closest maturity is one month ahead - the first month maturity is used as a proxy for the spot price. In Tables 3.7 and 3.8, we present descriptive statistics for each nearby. In line with the Samuelson effect, and in agreement with our findings in the previous subsection, nearby Futures contracts further in time have a lower standard deviation

Table 3.8
Descriptive Statistics for wheat nearby Future contracts, F1 to F17.

WHEAT	F1	F2	F3	F4	F5	F6	F7	F8	F9
Mean	6.10	6.12	6.13	6.14	6.15	6.16	6.17	6.17	6.17
Median	6.04	6.05	6.07	6.08	6.09	6.10	6.11	6.12	6.12
Maximum	7.06	7.06	7.06	7.01	6.96	6.97	6.98	6.98	6.98
Minimum	5.48	5.50	5.53	5.55	5.58	5.60	5.61	5.63	5.65
Std. Dev.	0.42	0.42	0.41	0.41	0.41	0.41	0.40	0.40	0.40
Skewness	0.24	0.24	0.24	0.24	0.23	0.23	0.23	0.23	0.23
Kurtosis	1.77	1.75	1.72	1.69	1.65	1.62	1.60	1.58	1.57
Jarque-Bera	11.65	12.05	12.41	13.00	13.63	14.06	14.46	14.79	15.01

WHEAT	F10	F11	F12	F13	F14	F15	F16	F17
Mean	6.18	6.18	6.19	6.19	6.20	6.20	6.21	6.21
Median	6.13	6.14	6.14	6.15	6.16	6.16	6.17	6.17
Maximum	6.98	6.98	6.99	6.99	6.99	6.98	6.93	6.91
Minimum	5.66	5.68	5.68	5.68	5.67	5.68	5.70	5.68
Std. Dev.	0.40	0.40	0.40	0.39	0.39	0.39	0.39	0.39
Skewness	0.23	0.23	0.23	0.24	0.23	0.23	0.22	0.22
Kurtosis	1.57	1.56	1.56	1.55	1.54	1.52	1.49	1.47
Jarque-Bera	15.16	15.29	15.37	15.49	15.71	16.00	16.51	16.92

Note: All Jarque-Bera statistics are significant at the 1% level, meaning we cannot accept the null hypothesis of zero skewness and excess kurtosis, i.e. the sample is not from a normal distribution.

We proceed by testing the REH using cointegration analysis and VECM for individual nearby Future contracts and check their ability to predict the future spot price as they lie farther in the past, for example, if the 4^{th} month maturity predicts four months ahead. We then consider several models that contain several maturities as predictors of future spot prices (See Table 3.9). Models 1, 2, 3, and 7 consider a number of lagged Future prices while models 4, 5, and 6 are a linear combination of selected lagged Futures contracts that reflect the fact that liquid maturities are unequally spaced in time. Hence, they bear a closer relationship to reality, in contrast to studying individual Future contracts resulting from the interpolation.

Table 3.9
Models considered for the VECM

Model	Variables included
1	F1, F4, F6
2	F1, F4, F6, F9
3	F1, F4, F6, F9, F12
4	F1, F4, F5, F6
5	F1, F6, F7, F8
6	F1, F9, F10
7	F1, F4, F5, F6, F7, F8, F9, F10, F11, F12

Before proceeding with the cointegration analysis, we test each time series for stationarity using the standard Philips-Perron (1988) and Augmented Dickey-Fuller (1979) tests. We find that all of our times series are non-stationary at levels and are stationary after taking first differences, i.e., they are integrated of order one I(1), pre-conditions for cointegration testing and the VECM.

4.2.1 Cointegration analysis

We test for cointegration to identify the existence of a long term relationship between variables or price series. These tests are meant to differentiate between short and long term price variations. If two series are cointegrated, they move together over an extended period of time, with fluctuations occurring over short periods. We use the Johansen cointegration test in order to identify all cointegrating vectors. Johansen (1991) develops a method that has clear advantages over the Engle and Granger approach. One advantage of the Johansen method is that the results are not dependent on the ordering of the variables and multiple variables can be tested.

The Johansen test starts estimating a vector autoregression of order *k*, $X_t = \Pi_1 X_{t-1} + \cdots + \Pi_k X_{t-k} + \varepsilon_t$, where X_t is a p-dimensional vector and Π_1 is a p x p dimensional matrix, and ε_t is the vector of independently identically distributed errors. This expression can be represented in error correction form and hence, tests for cointegration focus in determining the rank of the matrix $\Pi = \beta\alpha'$, where α' is a p x r matrix of cointegrating vectors and β is a matrix of adjustment coefficients. Two tests can be used: the trace test, which uses the null hypothesis of the number of cointegrating equations being less than *r* against the alternative that $\lambda_{trace} = 0$, i.e., there are no cointegrating equations; and the maximum eigenvalue test, λ_{max}, which checks if the number of equations is *r* versus *r+1*. The maximum likelihood estimator is used to calculate the eigenvalues of Π.

We use several information criteria, including the Akaike information criterion (AIC), Bayesian criterion (BIC) and the Hannan-Quinn information criterion to choose the number of lags in VAR, which is an important pre-requisite when conducting the Johansen cointegration test. Too few lags can result in model misspecification and too many lags can result to a loss in degrees of freedom. Tables 3.10 and 3.11 present results for the Johansen cointegration test. In all cases, we can reject the null of no cointegrating relationships, r = 0, at the 5% level and accept the null hypothesis , r ≥ 1, that there exists at least one cointegrating relationship. Hence, there is one long-run relationship in each pairing of the spot with individual lagged nearbys and also of the spot with each of our seven models.

Table 3.10
Results of Johansen cointegration tests for corn and wheat, nearby Future contracts F1 to F17. Values for both the trace test maximum eigenvalue tests are included.

Variables	Hypo-thesis	Corn				Wheat			
		λ_{trace}	Critical Value	λ_{max}	Critical Value	λ_{trace}	Critical Value	λ_{max}	Critical Value
F1, F4	r = 0	21.43*	15.49	20.27*	14.26	53.42*	15.49	50.43*	14.26
	r ≥ 1	1.15	3.84	1.15	3.84	2.99	3.84	2.99	3.84
F1, F5	r = 0	16.56*	15.49	15.84*	14.26	48.89*	15.49	46.29*	14.26
	r ≥ 1	0.73	3.84	0.73	3.84	2.60	3.84	2.60	3.84
F1, F6	r = 0	21.01*	15.49	20.46*	0.54	32.00*	15.49	29.07*	14.26
	r ≥ 1	0.54	3.84	14.26	3.84	2.93	3.84	2.93	3.84
F1, F7	r = 0	86.43*	15.49	85.95*	14.26	31.18*	15.49	27.93*	14.26
	r ≥ 1	0.48	3.84	0.48	3.84	3.25	3.84	3.25	3.84
F1, F8	r = 0	59.89*	15.49	59.50*	14.26	27.93*	15.49	24.80*	14.26
	r ≥ 1	0.39	3.84	0.39	3.84	3.13	3.84	3.13	3.84
F1, F9	r = 0	46.71*	15.49	46.30*	14.26	22.35*	15.49	20.17*	14.26
	r ≥ 1	0.41	3.84	0.41	3.84	2.18	3.84	2.18	3.84
F1, F10	r = 0	34.02*	15.49	33.72*	14.26	22.81*	15.49	21.28*	14.26
	r ≥ 1	0.29	3.84	0.29	3.84	1.53	3.84	1.53	3.84
F1, F11	r = 0	22.96*	15.49	22.79*	14.26	18.05**	15.49	16.58**	14.26
	r ≥ 1	0.17	3.84	0.17	3.84	1.47	3.84	1.47	3.84

F1, F12	**r = 0**	17.13*	15.49	16.76*	14.26	19.18**	15.49	17.88**	14.26
	r ≥ 1	0.36	3.84	0.36	3.84	1.30	3.84	1.30	3.84
F1, F13	**r = 0**	16.22*	15.49	15.57*	14.26	18.51**	15.49	16.96**	14.26
	r ≥ 1	0.66	3.84	0.66	3.84	1.56	3.84	1.56	3.84
F1, F14	**r = 0**	18.48**	15.49	17.96**	14.26	20.06*	15.49	18.22**	14.26
	r ≥ 1	0.52	3.84	0.52	3.84	1.84	3.84	1.84	3.84
F1, F15	**r = 0**	16.00**	15.49	15.89**	14.26	23.38*	15.49	21.52*	14.26
	r ≥ 1	0.11	3.84	0.11	3.84	1.86	3.84	1.86	3.84
F1, F16	**r = 0**	19.46**	15.49	19.41*	14.26	17.22**	15.49	15.31**	14.26
	r ≥ 1	0.05	3.84	0.05	3.84	1.92	3.84	1.92	3.84
F1, F17	**r = 0**	15.72**	15.49	15.72**	14.26	19.56**	15.49	17.99**	14.26
	r ≥ 1	0.00	3.84	0.00	3.84	1.56	3.84	1.56	3.84

Notes: *, **, *** represents the rejection of the null at the 1%, 5%, and 10% level respectively.

Table 3.11
Results of Johansen cointegration tests for corn and wheat models 1 to 7. Values for both the trace test maximum eigenvalue tests are included.

Model	**Hypo-thesis**	**Corn**				**Wheat**			
		λ_{trace}	**Critical Value**	λ_{max}	**Critical Value**	λ_{trace}	**Critical Value**	λ_{max}	**Critical Value**
1	r = 0	12.96*	15.49	36.43*	21.13	142.42*	29.80	89.40*	21.13
	r ≥ 1	0.87	3.84	12.09	14.26	2.93	3.84	2.93	3.84
2	r = 0	88.77*	47.86	41.29*	27.58	188.58*	47.86	94.66*	27.58
	r ≥ 1	0.49	3.84	0.49	3.84	2.21	3.84	2.21	3.84
3	r = 0	10.40*	15.49	9.91*	14.26	236.95*	69.82	95.29*	33.88
	r ≥ 1	0.57	3.84	0.57	3.84	1.57	3.84	1.57	3.84
4	r = 0	107.63*	47.86	69.24*	27.58	1491.23*	47.86	937.25*	27.58
	r ≥ 1	11.34	15.49	10.23	14.26	2.94	3.84	2.94	3.84
5	r = 0	501.95*	47.86	445.15*	27.58	1325.36*	47.86	921.58*	27.58
	r ≥ 1	0.28	3.84	0.28	3.84	3.10	3.84	3.10	3.84
6	r = 0	79.23*	29.80	50.94*	21.13	486.09*	29.80	464.05*	21.13
	r ≥ 1	0.30	3.84	0.30	3.84	1.98	3.84	1.98	3.84
7	r = 0	558.05*	239.24	124.63*	64.50	6230.76*	239.24	1027.46*	64.50
	r ≥ 1	8.54	15.49	7.77	14.26	1.56	3.84	1.56	3.84

Notes: *, **, *** represents the rejection of the null at the 1%, 5%, and 10% level respectively.

4.2.2 Vector error correction model

Since cointegration exists in all cases, we can proceed to the vector error-correction model (VECM) as an acceptable representation of the data. While the Johansen cointegration test tells us if there is relationship over the long term, the VECM reveals short-term dynamics. Results are presented in Tables 3.12 and 3.13 for corn and in Tables 3.14 and 3.15 for wheat. We include the adjustment coefficients δ_1 in addition to several model diagnostics, including the R-squared, F-statistic, AIC and BIC. If δ_1 is negative and significant then F1 reacts to deviations from the long-term value, meaning that the VECM is valid. The sign of the coefficient is important because in the event that F1 is greater than its long-run value, the change in F1 should be negative to compensate for the disequilibrium.

Table 3.12
VECM results for corn, nearby Future contracts F1 to F17. Including β_0, the adjustment coefficients δ_1 and R-squared, F-statistic, AIC and BIC.

Error Correction Model: $\Delta S_t = \delta_o + \delta_1(S_{t-1} - \sum_{i=1}^{I} \hat{\beta}_i F_{i,t-i} - \hat{\beta}_0) + \varepsilon_t$						
Corn Variables	β_0	δ_1	R^2	**F-statistic**	**AIC**	**BIC**
F1, F4	-0.002 (0.013) [-0.130]	-0.454 (0.395) [-1.148]	0.058	0.801	-1.841	-1.617
F1, F5	-0.002 (0.012) [-0.129]	-0.351 (0.273) [-1.286]	0.063	0.881	-1.846	-1.623
F1, F6	-0.001 (0.014) [-0.108]	-0.305 (0.241) [-1.262]	0.079	0.733	-1.783	-1.467
F1, F7	0.005 (0.009) [0.569]	-0.114*** (0.066) [-1.718]	0.057	0.786	-1.840	-1.616
F1, F8	0.007 (0.009) [0.790]	-0.077 (0.053) [-1.450]	0.052	0.712	-1.834	-1.610
F1, F9	0.006 (0.009) [0.723]	-0.084*** (0.044) [-1.908]	0.056	0.778	-1.839	-1.615

F1, F10	0.009 (0.009) [0.990]	-0.066*** (0.039) [-1.663]	0.056	0.778	-1.839	-1.615
F1, F11	0.009 (0.009) [1.041]	-0.064*** (0.037) [-1.736]	0.060	0.835	-1.843	-1.619
F1, F12	0.007 (0.009) [0.868]	-0.055 (0.035) [-1.599]	0.077	1.078	-1.861	-1.637
F1, F13	0.007 (0.009) [0.808]	-0.050 (0.033) [-1.516]	0.082	1.164	-1.867	-1.643
F1, F14	0.008 (0.009) [0.827]	-0.054 (0.038) [-1.406]	0.105	0.842	-1.772	-1.408
F1, F15	0.007 (0.009) [0.754]	-0.064 (0.039) [-1.624]	0.126	0.894	-1.756	-1.344
F1, F16	0.011 (0.010) [1.189]	-0.061 (0.041) [-1.511]	0.146	0.915	-1.735	-1.275
F1, F17	0.014 (0.009) [1.518]	-0.041 (0.037) [-1.104]	0.136	0.968	-1.766	-1.355

Note: Standard errors are in parentheses and t-statistics are in brackets. *, **, and *** denotes significance at the 1%, 5%, and 10% level

Table 3.13
VECM results for corn, models 1 to 7. Including β_0, the adjustment coefficients δ_1 and R-squared, F-statistic, AIC and BIC.

Corn Model	**β_0**	**δ_1**	**R^2**	**F-statistic**	**AIC**	**BIC**
1	0.010 (0.009) [1.139]	0.002 (0.601) [0.003]	0.075	0.703	-1.796	-1.482
2	0.013 (0.009) [1.364]	0.211 (0.727) [0.290]	0.087	0.61	-1.746	-1.343
3	0.012 (0.009) [1.251]	0.054 (0.137) [0.397]	0.124	0.709	-1.724	-1.232
4	0.004 (0.009) [0.475]	1.535 (1.037) [1.480]	0.103	0.737	-1.764	-1.361
5	0.009 (0.009) [1.021]	-0.172*** (0.100) [-1.727]	0.077	0.539	-1.736	-1.332
6	0.014 (0.009) [1.607]	-0.087*** (0.042) [-2.080]	0.105	1.024	-1.829	-1.516
7	0.001 (0.015) [0.476]	0.476 (0.545) [0.873]	0.221	0.587	-1.526	-0.586

Note: Standard errors are in parentheses and t-statistics are in brackets. *, **, and *** denotes significance at the 1%, 5%, and 10% level

First, we look at the case of corn. For the pairings of the spot with single nearbys (see Table 3.12), the adjustment coefficients for F1 pairings with F7, F9, F10, and F11 are both negative and significant at the ten percent level. Models 5 and 6 (See Table 3.13) also show a negative coefficient with significance at the ten percent level. If we look at the AIC and BIC to evaluate the quality of these models, the pairing F1, F7 is the best since it has the lowest AIC and BIC values, -1.840 and -1.616 respectively.

Second, we look at the case of wheat. For the pairings of spot with single nearbys (see Table 3.14), the adjustment coefficients for F1 pairings with F14, F15, F16, and F17 are both negative and significant at the ten percent level. The pairing with F14 is the best model according to the AIC and BIC criterion, with values of -1.680 and -1.410 respectively. These values decrease with increasing maturity. There are no significant coefficients in Models 1 to 7 (See Table 3.15).

Table 3.14
VECM results for wheat, nearby Future contracts F1 to F17. Including β_0, the adjustment coefficients δ_1, R-squared, F-statistic, AIC and BIC.

Error Correction Model: $\Delta S_t = \delta_o + \delta_1 (S_{t-1} - \sum_{i=1}^{I} \hat{\beta}_i F_{i,t-i} - \hat{\beta}_0) + \varepsilon_t$						
Wheat Variables	**β_0**	**δ_1**	**R^2**	**F-statistic**	**AIC**	**BIC**
F1, F4	0.008 (0.009) [0.908]	-0.028 (0.057) [-0.490]	0.002	0.240	-1.790	-1.746
F1, F5	0.008 (0.009) [0.910]	-0.050 (0.050) [-1.004]	0.008	1.009	-1.796	-1.752
F1, F6	0.008 (0.009) [0.907]	-0.018 (0.045) [-0.403]	0.001	0.162	-1.790	-1.746
F1, F7	0.008 (0.009) [0.907]	-0.004 (0.041) [-0.099]	0.000	0.010	-1.789	-1.745
F1, F8	0.008 (0.009) [0.907]	-0.007 (0.037) [-0.199]	0.000	0.039	-1.789	-1.745
F1, F9	0.008 (0.009) [0.910]	-0.032 (0.035) [-0.932]	0.007	0.868	-1.795	-1.751
F1, F10	0.010 (0.009) [1.116]	-0.018 (0.038) [-0.471]	0.023	0.582	-1.752	-1.619
F1, F11	0.009 (0.009) [1.037]	-0.028 (0.036) [-0.786]	0.023	0.581	-1.752	-1.619

F1, F12	0.009 (0.009) [1.027]	-0.045 (0.035) [-1.272]	0.040	0.709	-1.730	-1.552
F1, F13	0.009 (0.009 [1.004]	-0.036 (0.035 [-1.028]	0.043	0.587	-1.694	-1.470
F1, F14	0.005 (0.010) [0.538]	-0.062*** (0.037) [-1.681]	0.066	0.734	-1.680	-1.410
F1, F15	0.005 (0.010) [0.505	-0.078*** (0.037) [-2.148	0.099	0.933	-1.676	-1.360
F1, F16	0.006 (0.010) [0.640]	-0.072*** (0.036) [-2.002]	0.093	0.871	-1.670	-1.353
F1, F17	0.006 (0.010) [0.613]	-0.078*** (0.037) [-2.084]	0.095	0.753	-1.634	-1.270

Note: Standard errors are in parentheses and t-statistics are in brackets. *, **, and *** denotes significance at the 1%, 5%, and 10% level

Table 3.15
VECM results for wheat, models 1 to 7. Including β_0, the adjustment coefficients δ_1, R-squared, F-statistic, AIC and BIC**.**

Wheat Model	**β_0**	**δ_1**	**R^2**	**F-statistic**	**AIC**	**BIC**
1	0.008 (0.009) [0.907]	-0.001 (0.008) [-0.114]	0	0.013	-1.789	-1.745
2	0.008 (0.009) [0.907]	-0.003 (0.007) [-0.352]	0.001	0.124	-1.789	-1.746
3	0.008 (0.009) [0.907]	-0.004 (0.009) [-0.429]	0.001	0.184	-1.79	-1.746
4	0.008 (0.009) [0.914]	0.000 (0.000) [-1.480]	0.017	2.19	-1.805	-1.761
5	0.008 (0.009) [0.909]	0.000 (0.000) [0.706]	0.004	0.498	-1.792	-1.748
6	0.008 (0.009) [0.908]	0.000 (0.001) [0.469]	0.002	0.22	-1.79	-1.746
7	0.008 (0.009) [0.907]	0.000 (0.000) [0.416]	0.001	0.173	-1.79	-1.746

Note: Standard errors are in parentheses and t-statistics are in brackets. *, **, and *** denotes significance at the 1%, 5%, and 10% level

4.2.3. Forecasting evaluation

As a final step, using the results of the error correction models during the estimation period, we perform out of sample forecasting evaluations (See Tables 3.16a and 3.16b). In order to compare the performance of our models, we use the MAE, RMSE, and U. For all three of these forecasting evaluation metrics, the smaller the value the better the performance of the model.

For corn, of the models that show a significant and negative adjustment coefficient, the pairing of F1 with F7 has the smallest values of all three forecasting measures. Hence, it has the highest predictive power in the REH framework. In the case of wheat, the pairing of F1 with F14 had the smallest AIC and BIC in the VECM diagnostic results and the smallest values of all three forecasting measures amongst the valid error correction models.

Tables 3.16a and 3.16b
Mean absolute errors (MAE), root mean square error (RMSE), and Theil's inequality coefficient (U) for individual nearby Future contracts (Top) and Models 1 to 7 (Bottom).

Variables	Corn			Wheat		
	MAE	**RMSE**	**U**	**MAE**	**RMSE**	**U**
F1, F4	0.1720	0.1995	0.0152	0.1258	0.1392	0.0105
F1, F5	0.1526	0.1682	0.0128	0.1308	0.1433	0.0108
F1, F6	0.1660	0.1826	0.0139	0.1230	0.1352	0.0102
F1, F7	0.0746	0.0894	0.0068	0.1202	0.1331	0.0100
F1, F8	0.0670	0.0856	0.0065	0.1200	0.1327	0.0100
F1, F9	0.0767	0.0957	0.0073	0.1176	0.1298	0.0098
F1, F10	0.0766	0.0944	0.0072	0.1119	0.1249	0.0094
F1, F11	0.0759	0.0929	0.0071	0.1811	0.2503	0.0204
F1, F12	0.0611	0.0823	0.0063	0.1221	0.1303	0.0098
F1, F13	0.0625	0.0836	0.0064	0.1189	0.1271	0.0095
F1, F14	0.0625	0.0824	0.0063	0.0963	0.1086	0.0082

F1, F15	0.1186	0.1325	0.0102	0.1204	0.1325	0.0100
F1, F16	0.2051	0.2194	0.0169	0.1290	0.1430	0.0107
F1, F17	0.2102	0.2259	0.0175	0.1383	0.1506	0.0113

Model	**Corn**			**Wheat**		
	MAE	**RMSE**	**U**	**MAE**	**RMSE**	**U**
1	0.0895	0.1018	0.0078	0.1206	0.1341	0.0101
2	0.0803	0.0919	0.0070	0.1367	0.1810	0.0138
3	0.0907	0.1131	0.0086	0.1231	0.1357	0.0102
4	1.3418	2.0295	0.1685	0.1227	0.1345	0.0102
5	0.0954	0.1127	0.0086	0.1194	0.1333	0.0100
6	0.1293	0.1468	0.0111	0.1174	0.1305	0.0098
7	0.3833	0.5059	0.0396	0.1195	0.1326	0.0100

4.3 Optimal lags of prediction of Future contracts

In this section, we leave the framework of the REH, in order to find the best lag of prediction for each nearby Futures contract. In contrast to the REH, which establishes that each nearby would have predictive power only at their respective maturity, we look for the lag that has the highest predictive power – the “optimal lag”. Due to the fact that in agricultural commodities we deal with unequally spaced maturities, we can establish a distinction between the lags with the most predictive power obtained from the interpolated nearby Future contracts, which we define as the “theoretical optimal lag”, and the results from a commodity with all traded maturities equally spaced in time. In our case, the use of interpolation implies that we may or may not have a corresponding traded maturity, while for other commodities with equally spaced traded contracts no interpolation would be necessary and the “theoretical optimal lag” and the “optimal lag” would be the same. In Table 3.17, we depict the available traded maturities on the CBOT for wheat and corn and their distance in months, *h*, to the spot price.

Table 3.17
Relationship between individual contracts for corn and wheat traded on the CBOT (March, May, July, September and December), their location in the forward curve (T_1 Spot, T_2, T_3, etc.) and their distance to the spot price in months, *h*.

Location in the curve	Observed Prices at t-h and corresponding h for each maturity									
T_1(Spot Price):	**Mar**	**h**	**May**	**h**	**Jul**	**h**	**Sep**	**h**	**Dec**	**h**
T_2	May	2	Jul	2	Sep	2	Dec	3	Mar	3
T_3	Jul	4	Sep	4	Dec	5	Mar	6	May	5
T_4	Sep	6	Dec	7	Mar	8	May	8	Jul	7
T_5	Dec	9	Mar	10	May	10	Jul	10	Sep	9
T_6	Mar	12	May	12	Jul	12	Sep	12	Dec	12
T_7	May	14	Jul	14	Sep	14	Dec	15	Mar	15

For this analysis, we extend the methodology proposed by Muth (1961) with a non-parametric test, the Wilcoxon signed-rank test, which allows for the absence of the strict assumptions needed to apply the F-test, such as the absence of serial correlation, which is present in both commodities. This test also takes into account the magnitude of the changes in the comparison of both distributions (Campbell and Dufour, 1991). We adapt equations (5) and (6) to find the “theoretical optimal lag” among the first 24 lags for each nearby:

$$\ln S_t = \alpha + \beta \ln F_{t-i} + \varepsilon \qquad (5a)$$

$$\ln S_t - \ln S_{t-i} = \alpha + \rho \quad (\ln F_{t-i} - \ln S_{t-i}) + \varepsilon \qquad (6a)$$

with *i* = 1,2,3,…,24 months. Additionally, we extend the methodology proposed by Muth (1961) with a non-parametric test, the Wilcoxon signed-rank test, which allows for the absence of the strict assumptions needed to apply the F-test. This test also takes into account the magnitude of the changes in the comparison of both distributions (Campbell and Dufour, 1991).

In the case of CBOT Corn, we observe that the “theoretical optimal lags” are always lower than the corresponding maturity (see Table 3.18). Lower optimal lags indicate that the best predictions correspond to future spot prices that happen earlier. In contrast, in the case of CBOT Wheat, the “theoretical optimal lags” from F4 to F11 are higher, i.e. individual Future contracts offer a better prediction of later future spot prices, while F12 maturities expiring one year ahead offer a twelve month prediction (see Table 3.19).

Table 3.18
“Theoretical optimal lag” for CBOT Corn, including corresponding F-tests with p-values, Wilcoxon signed-rank test, R-squared, Adjusted R-squared, AIC and BIC.

Variables	Theoretical Optimal Lag	F-test 1	p-value	F-test 2	p-value	Wilcoxon Test	p-value
F1, F4	3	0.375	0.69	0.384	0.68	5616	0.31
F1, F5	4	0.407	0.67	0.273	0.76	5545	0.31
F1, F6	5	0.362	0.70	0.163	0.85	5410.5	0.32
F1, F7	6	0.218	0.80	0.173	0.84	5354	0.33
F1, F8	7	0.138	0.87	0.236	0.79	5408	0.46
F1, F9	8	0.080	0.92	0.252	0.78	5518	0.59
F1, F10	8	0.046	0.95	0.118	0.89	5313	0.43
F1, F12	10	0.007	0.99	0.036	0.96	5557	0.84
F1, F14	11	0.137	0.87	0.004	1.00	5519	0.90
F1, F15	11	0.284	0.75	0.010	0.99	5402	0.83

Variables	Theoretical Optimal Lag	R-squared	Adj. R-squared	AIC	BIC
F1, F4	3	0.89	0.89	-127.445	-118.277

F1, F5	**4**	0.84	0.84	-74.973	-65.823
F1, F6	**5**	0.80	0.80	-40.178	-31.048
F1, F7	**6**	0.77	0.77	-19.323	-10.212
F1, F8	**7**	0.75	0.75	-3.706	5.385
F1, F9	**8**	0.72	0.72	10.399	19.471
F1, F10	**8**	0.72	0.72	10.066	19.138
F1, F12	**10**	0.69	0.68	28.309	37.341
F1, F14	**11**	0.67	0.67	34.302	43.313
F1, F15	**11**	0.68	0.67	32.353	41.365

Table 3.19
"Theoretical optimal lag" for CBOT Wheat, including corresponding F-tests with p-values, Wilcoxon signed-rank test, R-squared, Adjusted R-squared, AIC and BIC.

Variables	**Theoretical Optimal Lag**	**F-test 1**	**p-value**	**F-test 2**	**p-value**	**Wilcoxon Test**	**p-value**
F1, F4	**6**	5.376	0.01	0.507	0.60	5774	0.73
F1, F5	**7**	6.295	<0.01	0.541	0.58	5675	0.70
F1, F6	**7**	5.996	<0.01	0.360	0.70	5424	0.40
F1, F7	**9**	7.049	<0.01	0.080	0.92	5655	0.88
F1, F8	**10**	7.258	<0.01	0.029	0.97	5683	0.97
F1, F9	**11**	7.359	<0.01	0.059	0.94	5640	0.92
F1, F10	**11**	7.015	<0.01	0.100	0.90	5561	0.96
F1, F12	**12**	7.269	<0.01	0.038	0.96	5449	0.90
F1, F14	**13**	7.688	<0.01	0.041	0.96	5313	0.81

Variables	**Theoretical Optimal Lag**	**R-squared**	**Adj. R-squared**	**AIC**	**BIC**
F1, F4	**6**	0.754	0.753	-48.258	-39.147

F1, F5	**7**	0.709	0.708	-23.850	-14.759
F1, F6	**7**	0.711	0.709	-24.418	-15.327
F1, F7	**9**	0.638	0.635	7.227	16.279
F1, F8	**10**	0.61	0.608	16.909	25.941
F1, F9	**11**	0.586	0.583	24.591	33.603
F1, F10	**11**	0.585	0.582	25.113	34.125
F1, F12	**12**	0.563	0.56	31.225	40.217
F1, F14	**13**	0.546	0.543	36.006	44.977

These features could be explained by a fundamental difference in the global trade of corn and wheat. In the case of corn, world prices are usually set by the US domestic supply-demand forces and farmers in the Southern hemisphere, namely Argentina (generally the second largest exporter of corn), adjust their crop output in reaction to US corn harvests and prices (with US news during the summer curtailing the predictive power of the forward curves). Wheat, on the other hand, is grown in more places and climatic conditions - from cold environments near the Arctic Circle to tropical regions close to the Equator - than any other cereal grain. There are up to 20 species and more than 25,000 varieties of wheat in existence. Hence, CBOT Wheat (it is worth noting that although the CBOT Wheat Futures contract is linked to the price of No. 2 Soft Red Winter Wheat, it is generally used in hedging activities for all kinds of wheat) is less dependent on a single country of production, and the arrival of news from all over the world has an influence in the predictive power of the forward curves in the short term, although long term predictions are more reliable than in the case of CBOT corn.

4.4 Testing the geometric average $\bar{\mathrm{F}}$ as a predictor of future spot prices

In this section, we use the methodologies from Section 4.2 and 4.3 to test the geometric average of Future contracts as a predictor of future spot prices and compare its performance to previous models. The seasonal cost-of-carry model for commodity forward curves developed by Borovkova and Geman (2006) introduces the geometric average of the forward prices as an alternative to the spot price for the first state variable when managing a portfolio of seasonal or non-seasonal commodity Futures:

$$\bar{F} = \left(\prod_{T=1}^{N} F(t,T)\right)^{\frac{1}{N}} \qquad (7)$$

This quantity has the merit of being less volatile than the noisy spot price and is always observable.

Two other points are worth noting: first, if the N months encompass an integer number of calendar years, $\bar{F}$ is a measure that is, by construction, devoid of seasonality, as proposed by Borovkova and Geman (2006), who study seasonal energy commodities such as natural gas and heating oil. Second, in our setting, it seems reasonable to expect that the whole forward curve contains more information to build estimators of future spot prices than an individual Futures contract.

We compute $\bar{F}$ as the average of maturities across twelve months and provide two different constructions. In the first, $\bar{F}_1$ is built using F4 to F15, while F6 to F17 are used in the second construction, $\bar{F}_2$. We include this second construction since, in practice, it is usual to avoid the second traded nearby in the construction of $\bar{F}$.

Table 3.20
"Optimal lag" for CBOT Corn. Including corresponding F-tests with p-values, Wilcoxon signed-rank test, R-squared, Adjusted R-squared, AIC and BIC.

$\bar{F}$	Lag	F-test 1	p-value	F-test 2	p-value	Wilcoxon Test	p-value
$\bar{F}_1$	6	0.230	0.79	0.237	0.79	5295	0.23
$\bar{F}_2$	9	0.031	0.97	0.201	0.82	5497	0.66

$\bar{F}$	Lag	R-squared	Adj. R-squared	AIC	BIC
$\bar{F}_1$ $\bar{F}_2$	6 9	0.773 0.71	0.772 0.708	-19.285 16.459	-10.174 25.511

First, we follow the methodology presented in Section 4.3. to find the "optimal lag" of $\bar{F}$ (See Tables 3.20 and 3.21). Each $\bar{F}$ captures the difference in range of prediction found in the nearby Futures at their theoretical optimal lags, for instance, the $\bar{F}$ of wheat captures the fact that the best predictions are at later lags. Hence, in the case of wheat, the optimal lags of $\bar{F}$ are 9 and 11 respectively for each construction of $\bar{F}$, which are much higher than those of corn, with optimal lags of 6 and 9 respectively. These facts show the reliability of $\bar{F}$ throughout time and that $\bar{F}$ a better predictor than individual maturities for both wheat and corn markets.

Table 3.21
"Optimal lag" for CBOT Wheat. Including corresponding F-tests with p-values, Wilcoxon signed-rank test, R-squared, Adjusted R-squared, AIC and BIC.

$\bar{F}$	Lag	F-test 1	p-value	F-test 2	p-value	Wilcoxon Test	p-value
$\bar{F}_1$ $\bar{F}_2$	9 11	6.325 6.764	<0.01 <0.01	0.015 0.047	0.98 0.95	5558 5386	0.74 0.70

$\bar{F}$	Lag	R-squared	Adj. R-squared	AIC	BIC
$\bar{F}_1$ $\bar{F}_2$	9 11	0.636 0.586	0.634 0.583	7.982 24.576	17.034 33.588

We then study the properties of $\bar{F}$ with cointegration tests and VECM models as in Section 4.2. All our variables are I(1) and cointegrated (see Table 3.22), so the use of the VECM seems appropriate (see Table 3.23).

Table 3.22
Results of Johansen cointegration tests for corn and wheat with different constructions of $\bar{F}$.

Model	Hypothesis	Corn				Wheat			
		λ_{trace}	Critical Value	λ_{max}	Critical Value	λ_{trace}	Critical Value	λ_{max}	Critical Value
$F_1, \bar{F}_1$	r = 0	97.27*	0.38	96.89*	14.26	28.96*	15.49	27.50*	14.26
	r ≥ 1	15.49	3.84	0.38	3.84	1.46	3.84	1.46	3.84
$F_1, \bar{F}_2$	r = 0	35.45*	15.49	35.26*	14.26	24.14*	15.49	22.92*	14.26
	r ≥ 1	0.20	3.84	0.20	3.84	1.22	3.84	1.22	3.84

Table 3.23
Results of the VECM for corn and wheat with different constructions of $\bar{F}$.

Model	Corn					Wheat				
	β_0	δ_1	F-stat	AIC	BIC	β_0	δ_1	F-stat	AIC	BIC
$\boldsymbol{F_1, \bar{F}_1}$	0.006 (0.008) [0.767]	-0.120*** (0.062) [-1.946]	0.83	-1.902	-1.689	0.010 (0.009) [1.121]	-0.022 (0.045) [-0.493]	0.55	-1.73	-1.514
$\boldsymbol{F_1, \bar{F}_2}$	0.008 (0.008) [0.947]	-0.068 (0.039) [-1.769]	0.87	-1.883	-1.667	0.010 (0.009) [1.067]	-0.034 (0.038) [-0.892]	0.59	-1.717	-1.498

Note: *, **, *** represents the rejection of the null at the 1%, 5%, and 10% level respectively. Numbers in parentheses stand for the maximum likelihood standard errors. Numbers in brackets are t-statistics.

When we compare the results of our models containing geometric averages (See Table 3.23) with those studied in Section 4.2., in the case of corn the model $F_1, \bar{F}_1$ is the best model, with a significant adjustment coefficient of -0.120, AIC of -1.902 and BIC of -1.689. The model containing $\bar{F}_2$, despite having a non-significant adjustment coefficient of -0.068, has the second lowest values of AIC and BIC, -1.883 and -1.667 respectively. For wheat, same as in most cases which use individual nearby Future contracts in the REH framework, neither of the two models containing geometric averages are significant,. In Table 3.24, we present the out of sample results for the corn and wheat VECM models.

Table 3.24
Forecasting performance for corn and wheat for different constructions of $\bar{F}$

Model	Corn	Wheat

	MAE	RMSE	U	MAE	RMSE	U
$F_1, \overline{F}_1$	0.0877	0.1019	0.0078	0.1212	0.1301	0.0098
$F_1, \overline{F}_2$	0.0758	0.0940	0.0072	0.1212	0.1296	0.0097

5. Conclusion

This chapter presents two important issues highly relevant for policymakers and regulators, since both provide better warning signals with regards to rising food prices. First, we illustrate several measures of dispersion and we argue in favour of alternative estimators of price dispersion in corn and wheat markets, namely the consideration of the coefficient of variation and standard deviation of prices, since their levels are the quantities defining the cost of food supply for populations around the world. The repeated crises since 2006 have brought focus on the right entity of concern, namely the price prevailing in the world market, since price levels are reflected in the cost of food and food security for individuals who are not investors. Second, we analyze the performance of several forward measures as predictors of future spot prices. We do this not just in the classical REH framework but also in terms of the predictive power of Futures contracts at several lags. Our investigation yields several interesting results. We learn that the predictive power of individual forward maturities is greatly reduced in times of planting, heading, and harvesting. We also observe that corn and wheat differ in the fact that nearby Future contracts in corn usually predict at earlier lags than those of wheat. Finally, when we compare the average value of all liquid forward contracts with several VECM models and individual maturities, we find that the average value of forward contracts captures the previous properties for corn and wheat and also provides several advantages over the use of forward prices of individual maturities, since by construction it is a more reliable measure.

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Chapter 4. Introducing distances between forward curves: the example of the cattle market

1. Introduction

Raising cattle for meat and leather can be traced back at least 8,500 years to Europe and the Middle East. European settlers introduced cattle in the Americas at the time of Christopher Columbus. Eventually, large ranches developed from Canada to northern Mexico and from Venezuela to Argentina. Today, raising cattle for meat production takes place on a global scale. The current world count is approximately 1.3 billion heads of cattle. The biggest producers are the US, which makes up 25 per cent of world production, and Brazil, which accounts for 20 percent. China and India follow, with global production of 12 and 6 per cent respectively. The world's top exporters are Australia and Brazil, with main export markets including the EU-27, Russia, and Chile. Interestingly, despite Australia being one of the main world exporters, it does not have a Futures market for live cattle.

Cattle markets are an important matter from the perspective of food improvement worldwide and meat production is on the minds of governments that want to offer better food to their populations. The growing middle classes in emerging countries generally desire a richer diet with higher protein content and as populations in countries such as China and Brazil become richer, the appetite for meat and poultry increases. According to the Food and Agriculture Organization, the total meat consumption per capita in emerging countries will double by 2050. Meanwhile, dietary preferences are also changing the kind of beef demanded in the US, the country with the highest consumption of beef per capita - approximately 28 kg per year - because of a more health conscious population that requires higher quality products and more information regarding the food production processes. In addition to changing diets, the economic environment affects demand for meat. For example, cheaper cuts of meat are in higher demand during times of recession. Seasons also play a role, as cuts suitable for roasts are more sought after in winter, and ground beef is more desired in warmer months for barbecues.

In this chapter, we focus on the live cattle markets of US and Brazil, which are the most important cattle markets in the world based on size and volume of exports. Given their global importance, an understanding of the relationship between spot and forward prices in these two regions is essential, which has not yet been addressed in the academic literature. Our investigation is highly relevant, given the growing importance of this agricultural commodity at a time when a greater number of human beings, particularly from developing countries, can afford to include meat in their diets.

Our contributions are twofold. First, we describe the main properties of the US and Brazilian cattle markets, since, like fertilizers (Geman and Vergel

Eleuterio, 2013), this topic has essentially been unstudied in the financial literature. We use structural break analysis, cointegration, and Granger causality to investigate the relationship between the two largest cattle markets. Second, we identify trading strategies based on the forward curves associated with the two main cattle exchanges in the world, namely the Chicago Mercantile Exchange (CME) in the US and the BM&F Bovespa in Brazil. For this purpose, we introduce two measures of distance between forward curves, which allow us to take into consideration the information contained in the entirety of the forward curves. Using a measure of distance, we use the property of integration of the US and Brazilian live cattle markets in the period 2007-2013 to devise a profitable strategy related to trading pairs of Futures contracts. We compare our results to well-documented pairs trading strategies, which illustrates the superiority of our strategy.

The rest of the chapter is organized as follows. Section 2 gives an overview of the cattle markets and their main fundamentals. In Section 3, we study the structural breaks in Brazil and US live cattle spot prices. Section 4 analyzes the relationship between Brazil and US spot prices, while in Section 5 we introduce a new approach to study their integration by considering the distance between the forward curves in the two markets. We also develop a profitable pairs trading strategies across the two markets. Section 6 concludes.

2. Fundamentals of Live Cattle Markets

Since Futures prices and forward curves are directly linked to the realities of the physical markets themselves, in this section we provide the reader with the essential background needed to understand the live cattle markets. Explanations of the physical commodities are vital in order to be able to see how Futures prices are capturing the market.

2.1. Physical markets

The US is the largest producer of beef because of its abundance of feed grains and pasture land for cattle grazing. It is currently a net exporter of beef, although it also imports meat from Canada and Mexico, due to their proximity, and cooked beef products from Argentina and Brazil. US beef is mainly marketed as high quality cuts; grain-fed beef is primarily used for domestic and export use, while imports consist of lower quality grass-fed beef destined for processing. Hence, dietary changes, such as a reduction in the demand of products with ground beef, can result in variations in the import/export ratio. Brazil is the largest exporting country by volume and value, primarily from the sale of lower value cuts. It ranks second to the US in terms of beef production. Like the US, Brazil has a large amount of land suitable for cattle, in addition to abundant supplies of low cost feed, water, and labor.

The usual age for cattle to be categorized as live cattle is above two years, and CME and BM&F Bovespa Live Cattle Future contracts specify that the age of the livestock cannot exceed 42 months, or 3.5 years. Age is an important factor, since the tenderness of the meat decreases as age increases. Ranchers traditionally breed their cattle in summer. Calves are born in the spring following a gestation period of nine months (on average, a calf weighs 70 to 90 pounds at birth). After weaning, calves are sent to graze for up to nine months and, in this manner, gain the required weight of 650 to 850 pounds needed for transfer to the feedlot as “feeder cattle”. They typically remain in the feedlot for three to four months until they reach the required weight for slaughter (1,000 to 1,300 lbs) and become live cattle (Ryan, 2012).

Producers adapt herd sizes to the costs and expected prices of beef. Traders and farmers rely on the US Department of Agriculture (USDA) for pricing. For example, at the onset of the 2013 US government shutdown, the Chicago Mercantile Exchange (CME) stated that an extended closure of government services, including public reports published by the USDA containing information on Brazilian markets, could “interrupt or delay settlement prices of live cattle futures and options” (Wall Street Journal, 2013b).

Both weather and corn price - the main feed since it is the most efficient way to fatten feeder cattle - are important price determinants of live cattle. Dry conditions on pastures and harvested forage can greatly affect early stages in the calves’ development. For example, major droughts in the Farm Belt region of the US in 2011 and 2012 led to increased slaughter in order to cover costs due to affected pasture land and increased prices of feed grains (Wall Street Journal, 2013a). Reduced time in pasture due to higher feed costs leads to smaller sized cattle entering feedlots and, in turn, smaller sized cattle exiting feedlots. This results in lighter carcasses and lower average “dressed weights”, typically the weight of the skeletal and meat parts of the animal. Hence, the relationship between feeder cattle, corn, and live cattle is a fundamental tool for the participants in this market.

There are other factors that affect the long-term cyclical increases and decreases in cattle numbers. This period of expansion and decline is usually referred to as the “cattle cycle”, which averages 8 to 12 years and is the longest among all meat animals. In the last decade, outbreaks of Bovine Spongiform Encephalopathy (BSE), more commonly known as Mad Cow disease, and foot-and-mouth disease (FMD) resulted in severe reductions of herd sizes. Disease is one of the biggest impediments to beef trade and can result in prolonged trade bans and restrictions. The US has suffered several outbreaks of BSE. In Brazil, the occasional presence of FMD and lower sanitary conditions in slaughter houses eventually prevent exports of fresh, chilled, and frozen beef to the US, Canada, Mexico, Japan, South Korea, and Taiwan. Increasing herd size is a slow process due to biological constraints; the time required for breeding, birth, weaning, grazing, and feedlots is relatively inelastic. For example, the retention of female animals for breeding will result in reduced beef production in the short-term. Therefore, beef production is also directly related to the slaughter mix - the number of steers (castrated bulls), heifers (non-child bearing cows), and cows from feedlots intended for slaughter. Since steers have heavier carcasses than heifers or cows, a higher proportion of steers in the slaughter mix will most likely increase average weights. The same effect of higher average “dressed weights” occurs with dairy cows, since their average weight is higher than that of beef cows. Other factors that influence the cattle cycle include governmental policies associated with food safety, animal health, labeling of cattle and red meat products according to the country of origin, and obligatory reporting of prices.

2.2. Cattle as a semi-storable commodity

Fama and French (1987) study the convenience yield of several agricultural commodities including cattle and poultry. They use the fundamental relationship between spot and Future prices:

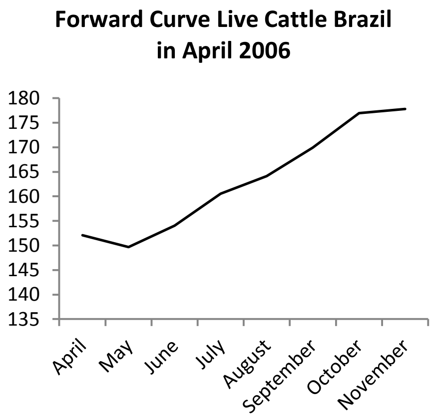
$$F(t,T) = S(t)e^{[r(t)+c(t,T)-y(t,T)](T-t)} \qquad (1)$$

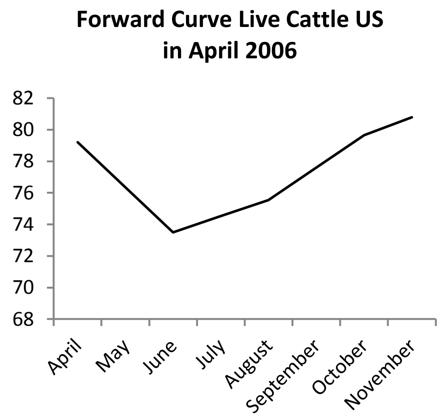
where *F(t,T)* is the Futures price, *S(t)* the spot price, *r(t)* the cost of financing and *c(t,T)* and *y(t,T)*, the cost of storage and the convenience yield respectively; the last three terms are expressed as rates (see Geman, 2005). The theory of storage (Kaldor, 1939 and Working, 1949) implies that the difference between the Future and spot prices (they call the ‘basis’) should be equal to the cost of carry (cost of financing plus costs of storage) minus the convenience yield. Following Kaldor (1949), Fama and French define the 'adjusted spread' as

$$\frac{F(t,T)-S(t)}{S(t)} = r(t)(T-t) + (T-t)c(t,T) - y(t,T)(T-t) \qquad (2)$$

and use it as a proxy for inventory to analyze the relationship between spot volatility and inventory. Geman and Nguyen (2005) validate on a database of world inventories the relationship between this adjusted spread and inventory in the case of soybeans.

Fama and French (1987) also argue that the standard deviation of the adjusted spread tells us if an individual commodity is consistent with the theory of storage, i.e., commodities that present high standard deviations are usually perishable products which are difficult to store and have seasonal variations in the convenience yield, while low standard deviations are present in commodities with no seasonality, such as metals. Analyzing a database ending in 1984, they found from the analysis of the adjusted spread of live cattle that this commodity is not very storable.





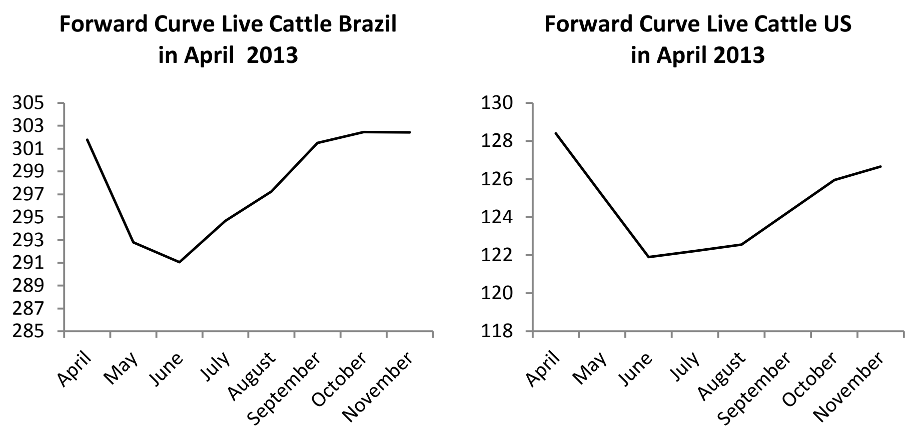


Figure 4.1. Forward curves from the first to 8th nearby Future contract for Brazil Live Cattle (in Reals per pound) and US Live Cattle (in US cents per pound)

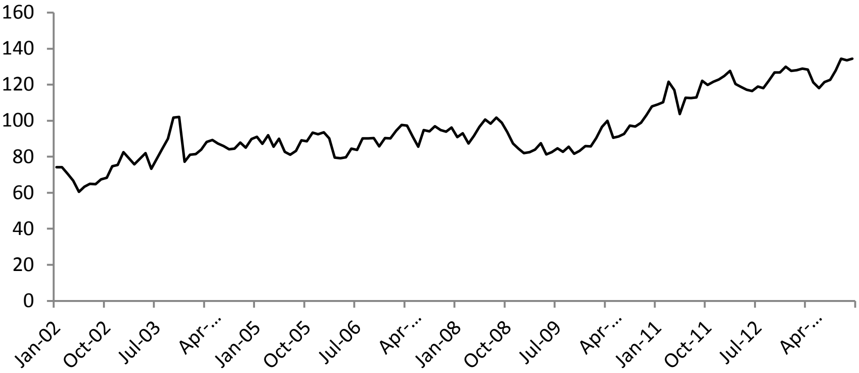
Following this approach, and in an ongoing situation of a small number of liquid maturities, we use the 6-month Future to compute the adjusted spread for the period from January 2002 to December 2013. We obtain standard deviations of 5.4 and 6.9 per cent for US and Brazilian live cattle respectively. These results are consistent with the result obtained by Fama and French of 5.6 per cent for US cattle for the period from January 1972 to July 1984. They are also in sharp contrast with commodities such as gold and silver, which present standard deviations of 2 and 1.5 per cent respectively. Hence, for all the above reasons, we can consider cattle as a semi-storable commodity.

3. Structural Breaks in the US and Brazil Live Cattle prices

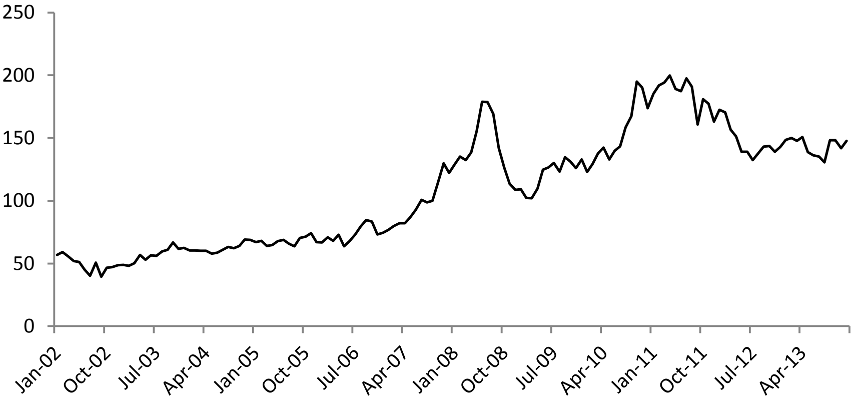
We now turn our attention to the two largest cattle Futures markets in the world. In order to analyze spot prices of Live Cattle, we use, in a classical manner, the first-nearby Future contracts in the CME and BM&F Bovespa as a proxy (see Figure 4.2).

We start with a structural break analysis. The existence of structural breaks can affect the econometric results, therefore they should be taken into account. For the purpose of investigating the existence of breaks in the trajectories, we use the Bai-Perron algorithm (Bai and Perron, 2003) for monthly log prices to identify potential break points in the time series. In other agricultural markets, Geman and Vergel Eleuterio (2013) exhibit synchronous breaks in corn and wheat prices in 2007, and a lagged one in fertilizer markets.

CME - Live Cattle - First Nearby
(in US cents per pound)



BM&F Bovespa - Live Cattle - First Nearby
(in US cents per pound)



BM&F Bovespa - Live Cattle - First Nearby
(in Brazilian Reals per net arroba)

Figure 4.2. CME Live Cattle prices (in US cents per pound) and BM&F Live Cattle prices (in US cents per pound and Brazilian Reals per net arroba, one net arroba = 15 kg) from January 2002 to December 2013

3.1. The US Live Cattle market

The US Live Cattle Future contract specifies physical delivery of 55 per cent ‘choice’ and 45 per cent ‘select’ yield grade 3 live steers. Choice and select refer to the degree of ‘marbling,’ the amount of intramuscular fat of young cattle up to 42 months. Categories from greatest to least amount of marbling for young cattle are prime, choice, select, and standard, and for older cattle include commercial, utility, and cutter. As an estimate of the percentage retail yield, yield grade is based on carcass weight, fat thickness at the 12th rib and rib-eye area, and percentages of kidney, heart and pelvic fat. Yield grade identifies the waste fat and ranges from grade 1, the most desirable, to grade 5 being the least desirable and excessively fat. Grade 3 is the industry average.

In CME Live Cattle, we find a structural break in October 2010 with a confidence interval from September 2010 to December 2010 and a reduction in the BIC from -76.16 to -238.34 (see Figure 4.3). This break occurs at a point of major change in the dynamics of the US live cattle industry, when the US changed from being a net importer to a net exporter.

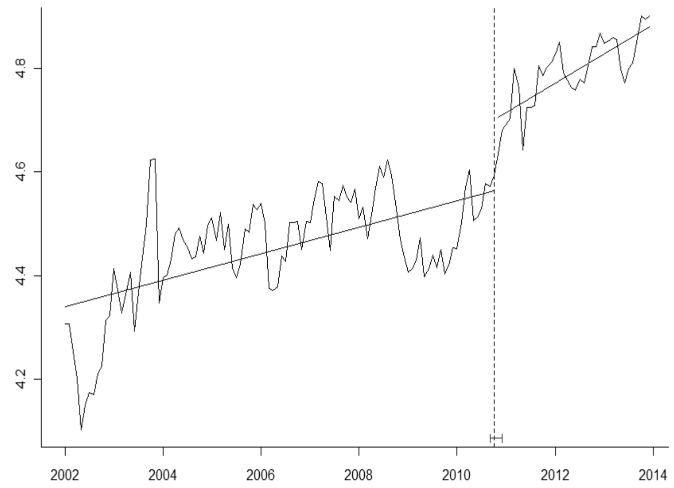


Figure 4.3. Structural break in CME Live Cattle log prices from January 2002 to December 2013

Upon discovery in December 2003 of the BSE illness, many countries prohibited imports of US beef. Hence, the export trade of the US, and also Canada where the BSE originated, was gravely affected. At the same time, the US beef cycle was at a low point in 2004, resulting in reduced domestic supplies of processed beef and a record high of total imports - 3.6 billion pounds according to the USDA. Herd building began in 2005 but stopped in 2006 due to drought and higher feed prices, which increased the number of cattle slaughtered throughout this period. In 2006, exports were less than half the volume of exports in 2003. It wasn’t until 2007 that trade recovered, following a number of events which included the containment of BSE, the growth of global demand for US beef products, a weakening US dollar, and tight supplies in worldwide inventories. All these elements contributed to the US transition from net importer to exporter. In 2011, according to USDA estimates, US beef cattle imports continued trending downwards while exports rose to 2.79 billion pounds - 32 million pounds more than imports - establishing the country as a net exporter (USDA, 2012). With an increase in domestic herd rebuilding since 2011 and a high demand for US beef in Asian countries, the trend of the US as a net exporter is expected to remain strong throughout 2014.

3.2. The Brazilian Live Cattle market

In contrast to the CME Futures contracts which are all physically settled, the Brazilian Futures contract traded on the BM&F Bovespa can either be physically or financially settled and only specifies carcass weight and maximum age, compared with the CME's specification of yield grade and degree of marbling.

The BM&F Bovespa Live Cattle Futures contract is priced in Brazilian Reals per net arroba, to two decimal places. For residents, margin requirements, trading costs and cash settlements are made in Brazilian Reals. For non-residents trading the Futures contracts, these quantities are payable/receivable in US Dollars. Therefore, to account for all traders who participate in this market, we conduct our initial analysis of structural breaks for the Brazilian futures contracts in both Brazilian Reals and US dollars. The analysis in latter sections will be solely in US dollars in order to present clear results in a common currency unit.

For BM&F Live Cattle (in Brazilian Reals), we find a structural break in October 2007 with a confidence interval from September 2007 to November 2007 and a reduction in the BIC from 49.94 to -199.28. When we look at the BM&F Live Cattle in US cents per pound, we find a structural break in June 2007 with a confidence interval from May 2007 to July 2007 and a reduction in the BIC from 187.93 to -66.57 (see Figure 4.4). The structural break in the live cattle prices in Reals can be associated with the replacement of Australia by Brazil in June 2007 as the largest world beef exporter in terms of monetary value.

It is clear from Figures 4.3 and 4. 4 that the respective structural breaks for US and Brazil live cattle prices represent points in time when prices began to move in a steep uptrend, and when both countries experienced increases in levels of exports.

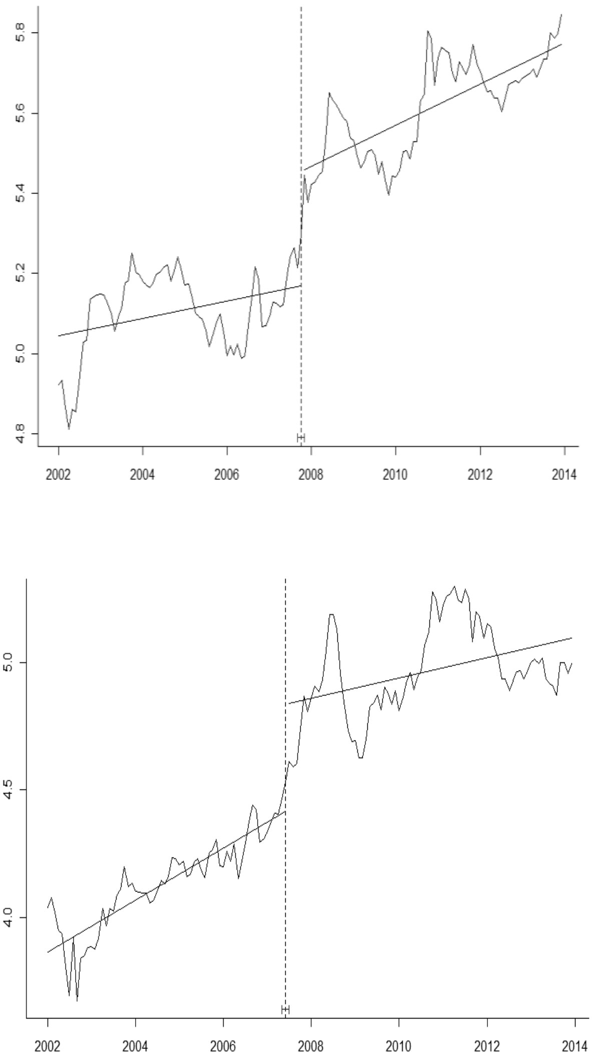


Figure 4.4. Top: Structural break in BM&F Live Cattle log prices (in Reals cents per pound). Bottom: Structural break in BM&F Live Cattle log prices (in USD cents per pound), from January 2002 to December 2013

From 2002 onward, the Brazilian meat industry has experienced rapid development, characterized by the introduction of a traceability system to comply with international requirements, an increase in slaughter rates from 11.6 per cent in 2002 to 24.1 per cent in 2010, and an increase in prices paid by packing plants from 1.12 USD to 3.29 USD per kilogram of beef (ANUALPEC, 2011). A rise in Brazilian exports was one of the main drivers in industry expansion. From 2002 to 2007, exports increased from 13.4 per cent to 28.2 per cent despite a marked decrease in calf production in 2007 caused by the slaughter of a large number of cows due to an FMD outbreak in 2005 (Millen et al., 2011). By 2008, the value of Brazilian exports reached 5 billion USD, twice the value of 2004. Since 2008, exports have decreased and by 2010, exports represented just 19.9 per cent of production, with 35 per cent of this percentage destined for European countries. An increase in exports to Europe was made possible by the certification of Brazilian farms in response to a 2006 ban by Europe of antibiotics in animal production, especially ionophores (growth enhancers), and the prohibition of beta-agonists.

3.3. Spot prices spread between US and Brazilian Live Cattle

We also analyze the structural breaks for the spot price spreads expressed both in dollar/cents and different currencies. In our period of study, there are two intervals where exchange rates make the spreads differ more widely, namely 2008-9 and 2012-13 (see Figure 4.5).

In the first spread, where both prices are expressed in US cents per pound, we find a structural break in September 2007 with a confidence interval from July 2007 to October 2007 and a reduction of the BIC from 1441.96 to 1255.89. For the second one, where both prices are expressed in their respective currencies, there is a structural break in October 2007 with a confidence interval from September 2007 to November 2007 and a reduction of the BIC from 1532.22 to 1259.73.

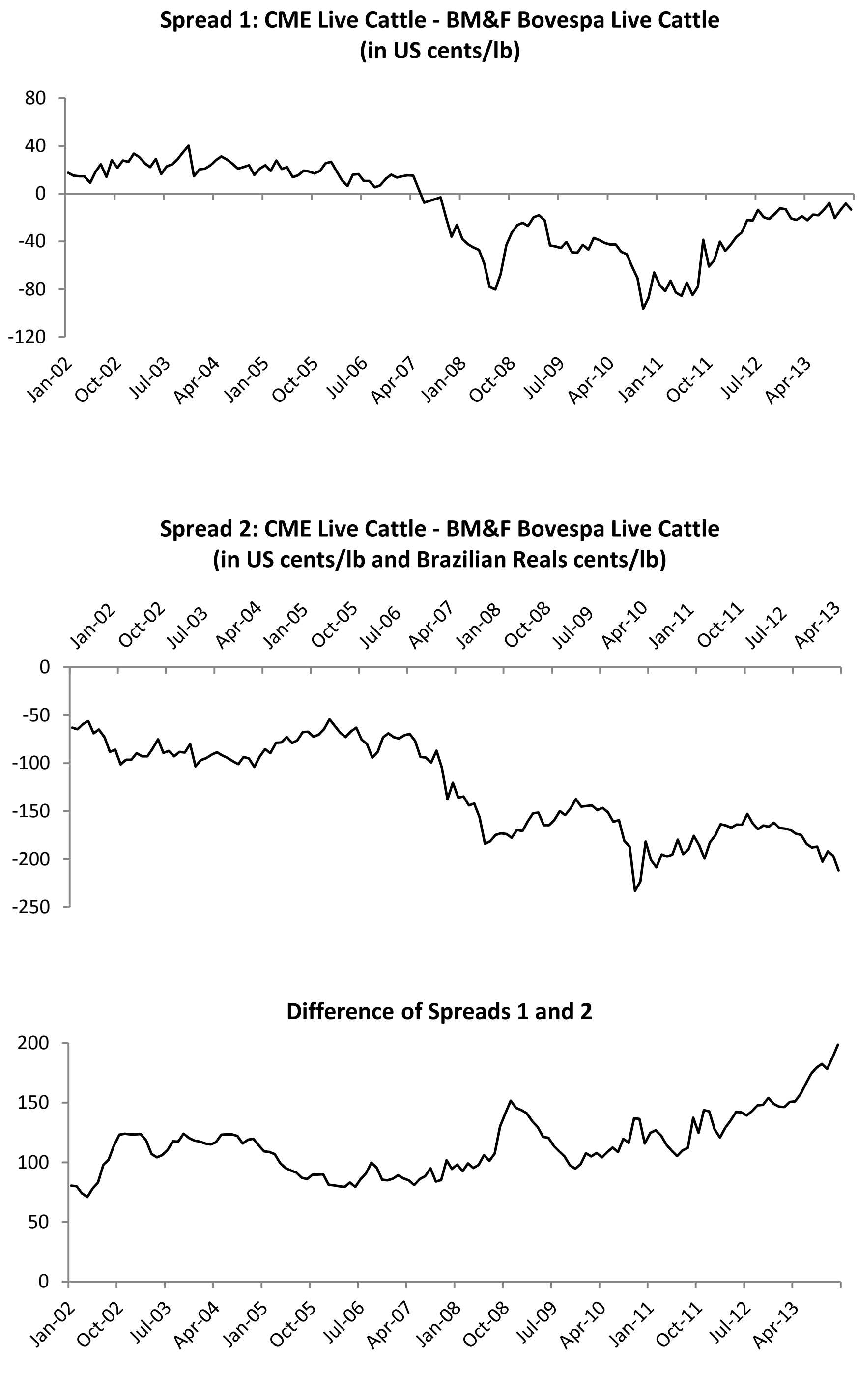


Figure 4.5. First Nearby spreads between CME and BM&F Live Cattle, and difference between the spreads

Our results show a remarkable synchronicity of breaks in the two spreads, irrespective of the exchange rates. We see that, despite the changes in the value of the Real against the dollar across the period 2002-2013, all of our results so far are essentially the same regardless of the currency we employ to analyse them, exhibiting their commodity-specific nature.

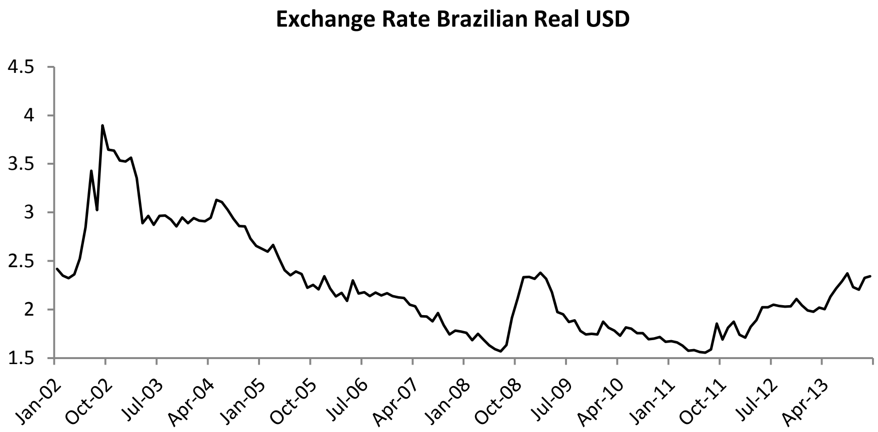


Figure 4.6. Exchange rate of Brazilian Reals per US Dollar, from Jan 2002 to December 2013

The reduced number of US exports - during most of the past decade the US was not a major international player – as well as the limited relations between the US and Brazil could explain why US dollars are not a significant driver in the comparison of the structural breaks. The USDA has just recently recommended the entry of Brazilian fresh beef products into the US. Therefore, factors other than currency may have a greater impact on prices, such as a restriction on exports due to health concerns. As it is well known, the depreciation of a country's currency typically makes it more competitive in the global market and helps sustain levels of exports to major importers. However, if a country is forbidden to export due to adverse production circumstances, this advantage is obviously lost.

4. Relationship Between US and Brazilian Live Cattle Spot Prices

To study the relationship between the US and Brazilian live cattle markets, we perform two kinds of analyses. Firstly, we study the Granger causality on price returns. Secondly, we study the cointegration of log prices, using the method developed by Engle and Granger (1987).

4.1. Granger causality

Due to the necessary condition of stationarity for the Granger causality tests (see Granger, 1969), we use price returns. In order to test Granger causality we run the regression:

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \ldots + \alpha_l y_{t-l} + \beta_1 x_{t-1} + \ldots + \beta_l x_{t-l} + \epsilon_t \quad (3)$$

The reported F-statistics are the Wald statistics for the joint hypothesis:

$$\beta_1 = \beta_2 = \ldots = \beta_l = 0 \quad (4)$$

As presented in Table 4.1, we test all possible combinations between CME Live Cattle returns and BM&F Live Cattle returns in US cents/lb, for the whole period and the two sub-periods obtained from the previous structural break analysis. Two criteria are used to select the optimal lag, the Akaike and Bayesian (or Schwartz) Criterion. In all cases, the optimal lag is lag one. In case A, we reject the null hypothesis for the whole period; this implies that price returns for Brazilian Live Cattle lead the relationship between Brazilian Live Cattle/ US Live Cattle. When causality is tested the other way (case B), we cannot reject the null hypothesis. Hence, there is no causality in the opposite direction, i.e., US Live Cattle returns do not lead Brazilian Live Cattle returns.

Table 4.1
Granger causality F-test results for CME Live Cattle and BM&F Live Cattle.

Test:	**A**	**B**
Null Hypothesis:	BM&F Live Cattle do not Granger Cause CME Live Cattle	CME Live Cattle do not Granger Cause BM&F Live Cattle
Whole Period	4.8819 **	2.6353
First Period	3.0625 *	0.82
Second Period	1.9528	2.0904

Note: (***) Denotes significance at 1%, (**) significance at 5%, and (*) significance at 10%.

When we study causality during the periods before and after the October 2007 structural break, we observe that the causality relationship only holds in one direction during the first period, i.e., the returns on Brazilian Live Cattle lead those of US Live Cattle.

4.2. Cointegration analysis between CME and BM&F live cattle markets

Tests for cointegration are used to identify the existence of a long term relationship between variables or price series. These tests are meant to differentiate between short and long term price variations. If two series are cointegrated, they move together over an extended period of time, with fluctuations occurring over short periods. Goodwin and Schroeder (1991) run cointegration tests for several US cattle markets. They are interested in the degree of cointegration between price series of regional cattle markets and the understanding of the factors driving the relationships in regional fed cattle markets. In our study, we go one step further by analyzing international markets and identifying the factors that explain their changing relationship over time, taking into account the existing structural breaks. In order not to blur the message in this section, we will be using the variables in their own currencies.

As a preliminary step, unit root tests are conducted for each of the time series in log prices and their first differences. If both series of log prices are I(1), i.e., they have unit roots and the first difference - series is stationary, making possible the use of the Engle and Granger methodology. We test all first-nearby Futures time series for stationarity by using two standard unit root tests: the test developed by Phillips and Perron (1988) and the augmented version of the unit root test by Dickey and Fuller (1979). Using both tests, the existence of I(1) processes is confirmed in all cases, so we can proceed to test for cointegration.

Engle and Granger propose a two-step procedure to establish if cointegration exists between two series. In theory, due to the asymptotic properties of the test, the choice of dependent variable affects the regression coefficients but not the distribution of the test statistics. In practice, the procedure is repeated with each of the variables as the dependent variable, especially for small samples and if the results are close to the critical values. In the first step, a linear regression is estimated:

$$y_t = \alpha + \beta x_t + e_t \qquad (5)$$

Estimates from the regression are used to calculate estimated residuals,

$$\hat{e}_t = y_t - \hat{\alpha} - \hat{\beta} x_t \qquad (6)$$

where the pair $\left[-\hat{\alpha}, -\hat{\beta}\right]$ is known as the cointegrating vector. Once the residuals are obtained, we check for cointegration by testing the residuals for stationarity.

The series are cointegrated if the relationship is I(0), i.e., there is no unit root. In this case, since only two variables are involved, we can use the ordinary Dickey Fuller (DF) - we do not need to use additional lags to account for serial correlation in the time series since the DF test uses the optimal lag obtained by BIC/SIC in all cases - and run the following regression:

$$\Delta\hat{e}_t = \alpha + \beta t + \gamma\hat{e}_{t-1} + \varepsilon_t \qquad (7)$$

We then use a t–test for γ=0 (see McKinnon, 2010).

Table 4.2
Results of Engle and Granger cointegration tests.

Whole Sample: from January 2002 to December 2013								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R^2**	**DF**	**P-value**
US Cattle	Brazil Cattle	1.725***	10.17	0.525***	16.63	0.66	-3.135	0.1
Brazil Cattle	US Cattle	-0.352	-1.02	1.259***	16.63	0.66	-2.907	0.2
First Period: from January 2002 to September 2007								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R^2**	**DF**	**P-value**
US Cattle	Brazil Cattle	0.794	1.46	0.711***	6.69	0.4	-4.622	<0.01
Brazil Cattle	US Cattle	2.611***	7.01	0.564***	6.69	0.4	-3.022	0.16
Second Period: from October 2007 to December 2013								
Dependent variable	**Indep. Variable**	**Intercept**	**t-ratio**	**Beta**	**t-ratio**	**R^2**	**DF**	**P-value**
US Cattle	Brazil Cattle	-1.108***	-2.28	1.026***	11.86	0.66	-4.192	<0.01
Brazil Cattle	US Cattle	2.627***	10.44	0.642***	11.86	0.66	-4.042	<0.01

Note: (***) Denotes significance at 1%, (**) significance at 5%, and (*) significance at 10%

In the first period, Brazilian live cattle log prices have a significant explanatory power on US Live Cattle with a p-value of less than 0.01 for the DF test. In the second period, the relationship becomes bidirectional and the variables are cointegrated (see Table 4.2). These findings are not only supported by the Engle and Granger approach but also by both types of

Johansen tests. i.e., trace and maximum eigenvalue tests. In the first period, Brazilian exports had a greater impact on world prices at a time when the US was a net importer. In other words, Brazil had a greater role in the price discovery of the world market, which could explain our results.

As a second step, Engle and Granger propose the estimation of an Error Correction Model. The estimation of this model allows us to establish, using first-differences, the speed of correction in the short-term, θ, while the long-term relationship is taken into account through the inclusion of the estimated residual$\hat{e}_{t-1}$:

$$\Delta y_t = \gamma \Delta x_t + \theta \hat{e}_{t-1} + u_t \qquad (8)$$

The existence of cointegration is supported if the parameter θ is negative, which shows the magnitude of the correction in one period - one month in our case.

Below, we present the estimated values of the Error Correction Model for the second period, when the time series are cointegrated. The dependent variable is the first difference of CME Live Cattle log prices, and the two independent variables are the first difference of BM&F Bovespa Live Cattle log prices and the lagged estimated residuals from equation (6):

$$\Delta y_t = 0.229\, \Delta x_t - 0.115 \hat{e}_{t-1} + u_t \qquad (9)$$

(0.105) (0.051)

The coefficient -0.115 tells us the speed at which the variables return to equilibrium after a short term shock, i.e., the value -0.115 indicates that 11.5% of the deviation of the variables from equilibrium is corrected in each month (the corresponding t-values are presented in parentheses below each estimated coefficient).

All tests agree in their results and indicate that while there is no cointegrating relationship in the first period, there exists a cointegrating relationship in the second period, which shows the growing relationship between US and Brazilian live cattle in more recent years, reflecting the rapid development of the live cattle markets in both regions (these results also fit with Granger causality results in Section 4.1). The US and Brazilian cattle markets have been expanding in recent years. In 2011, exports of US beef reached a record 2.8 billion pounds and expansion was reflected in a growing number of export destinations. Exports to Asia have increased, especially to Japan and a growing market in Hong Kong, Russia (although a ban on US beef was initiated in February 2013), Egypt, Vietnam, and Turkey. This is a substantial development considering that export destinations in 2007 consisted primarily of five countries - Canada, Mexico, Russia, South Korea, and Japan. Furthermore, with tight global supplies and an increasing volume of Australian exports going to China, exports will continue to outpace imports for the foreseeable future and the US will remain competitive with Brazil and other major beef exporting countries. The Brazilian market has also seen great improvements in growth and productivity. Several new markets are now open to Brazil. In addition to main export destinations including Russia, Hong Kong, the EU, and Egypt, beef is now exported from Brazil into Venezuela, Chile, and Iran. Jordan, Turkey, and Congo are also expected to increase beef imports from Brazil and countries including China and Saudi Arabia, which banned imports because of a BSE episode, are expected to resume imports in 2014 (USDA Brazil Annual, 2013).

5. Analysis of the Joint Dynamics of Live Cattle Forward Curves

In this section, we use forward prices and measures of distance between forward curves as a means to create a successful trading strategy that takes full advantage of the cointegrating relationship found in Section 4 and performs better than the classical pair trading strategies based solely on spot prices.

In the last decade, there has been a large increase in the popularity of commodities investing and the addition of commodities to investment portfolios. The classical way to gain exposure to commodities is through the use of Futures contracts (see Erb and Harvey, 2006), and their inclusion in positions held by investors makes the understanding of their dynamics of paramount importance.

5.1. Investing in asset pairs

The simplest way to gain exposure to upwards/downwards movements in a commodity spot price is to take a long/short position in a given Future contract. If the margin deposit is made of Treasuries, it gains some accrued interest, which adds to the benefit of the Futures trade.

A second and popular type of strategy is based on commodities' spreads, defined as a price difference between two commodities Futures. Popular spreads include the “crack spread” between futures contracts of crude oil, unleaded gasoline, and heating oil, as studied by Girma and Paulson (1999), and the “crush spread” which trades soybeans, soymeal, and soyoil futures. The latter spread is examined at length in a paper by Simon (1999). He gives many trading examples, for instance, when soybean contracts are thought to be undervalued compared with to meal and oil futures, a trader can profit by buying soybean futures and selling meal and oil futures at the same time.

Traditionally, Exchanges have provided spreads of closely linked commodities for trading, such as MGEX Wheat (Hard red spring wheat – Minneapolis Exchange) and KC HRW Wheat (Hard red winter wheat – Kansas City) at the CME. As there are many different Future markets around the globe, a commodity trader can either use the spreads on offer in the Exchanges or invest simultaneously in Future contracts of two commodities in order to gain exposure to the spread.

5.2. Measures of Distance between Live Cattle forward curves

To analyze the Futures curves of live cattle in the US and Brazilian markets, we use the last trading day of each month from January 2002 until December 2013, with data from Datastream. Real-denominated BM&F live cattle Futures maturities are available every month of the year. The CME only has six maturities for live cattle Futures, with delivery months in February, April, June, August, October, and December. In order to achieve consistent data series for comparison, we interpolate the CME data to create twelve monthly deliveries, respecting the "last trading day" rules. We select only the first eight maturities for our analysis due to the lack of liquidity in the more distant ones.

We use two measures of distance that provide distinct information about the relationship between US and Brazilian live cattle Futures markets. A first measure of distance between forward curves is naturally defined as the sum of the differences between forward prices for the same maturity.

$$First\ Measure\ of\ Distance = \sum_{j=1}^{8} |F_{CME\ Live\ Cattle}(t,T) - F_{BM\&F\ Live\ Cattle}(t,T)| \quad (10)$$

Using the distance between each forward contract has several advantages. It not only uses the first nearby but all price information available in the market. Other information can also be extracted from this measure, as exhibited in Figure 4.8.

Additionally, we introduce a second measure to analyze the joint dynamics of the forward curves. This measure consists of the ratio between the normalized first distance to the absolute value of the first nearby spread:

$$Second\ Measure = \frac{1}{N}\,\frac{\sum_{j=1}^{N}\left|F_{CME\ Live\ Cattle}(t,T)-F_{BM\&F\ Live\ Cattle}(t,T)\right|}{\left|F_{CME\ Live\ Cattle}(t,1)-F_{BM\&F\ Live\ Cattle}(t,1)\right|} \tag{11}$$

where the number of maturities, *N,* in each forward curve is eight. If the forward curves move together, the ratio will be very close to one, indicating that the information provided by the whole forward curve is the same as the one provided by the first nearby.

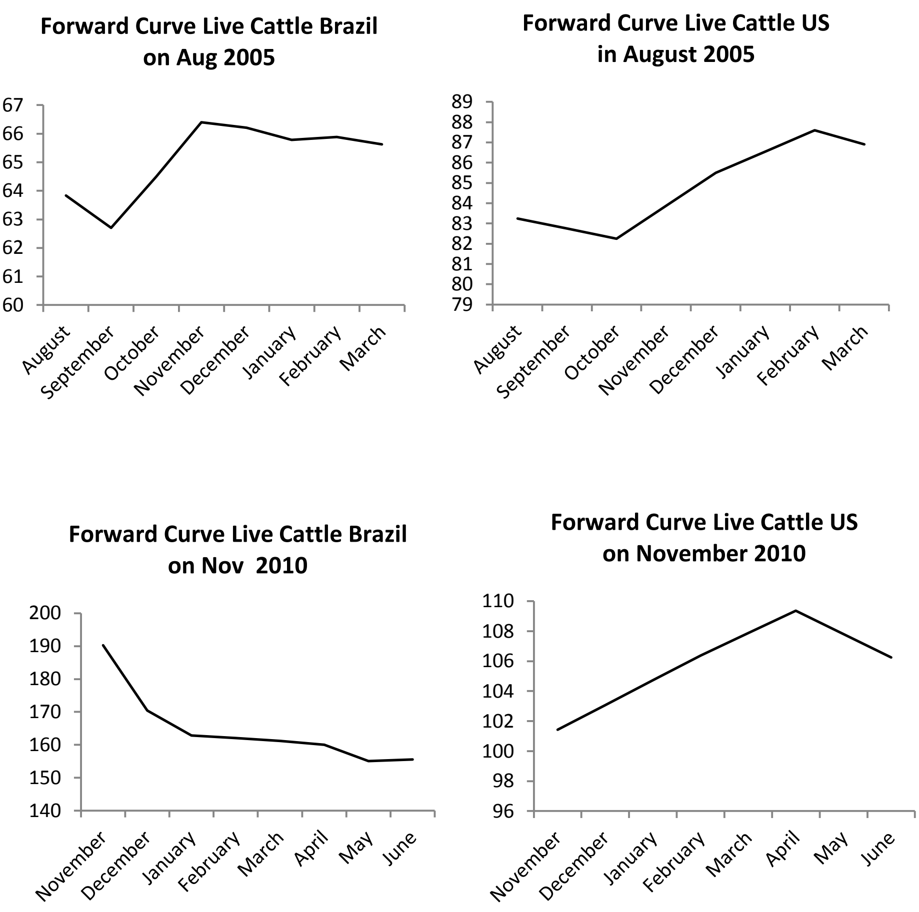
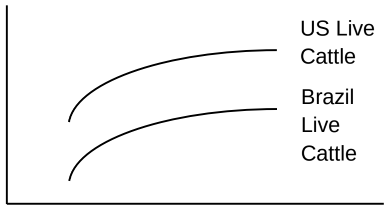
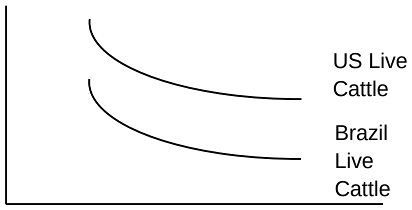


Figure 4.7. Forward curves from the first to 8th nearby Future contract for Brazil Live Cattle and US Live Cattle, both in US cents per pound.

Parallel US Live Cattle and Brazil Live Cattle curves

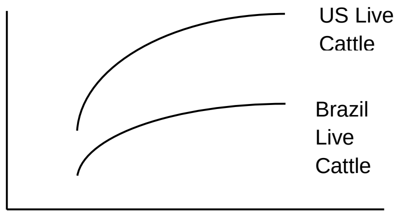


a.1. contango

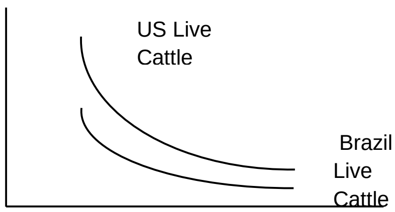


b.1 backwardation

US Live Cattle curve steeper than Brazil Live Cattle's

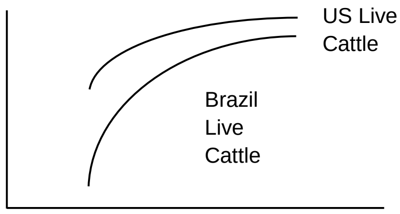


a.2. contango

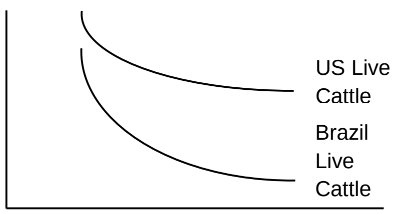


b.2. backwardation

Brazil Live Cattle curve steeper than US Live Cattle's

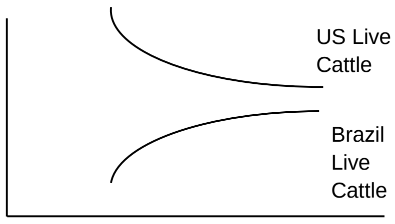


a.3. contango

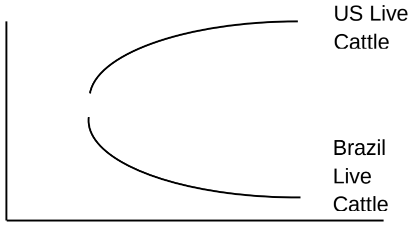


b.3. backwardation

Mixed shapes



a.4. Brazil contango, US backwardation



b.4. Brazil backwardation, US contango

Figure 4.8. Hypothetical shapes of forward curves with a positive spread for US and Brazil Live Cattle

We depict the first and second measure of distances for the whole period in Figure 4.9. The first measure exhibits a change in level in 2007-2008, which coincides with our previous analysis of structural breaks. In order to reinforce the message conveyed by the second measure, we compute its standard deviation with a rolling window of 12 months. The standard deviation is much lower as of 2007, indicating that the forward curves in the latter period are moving together.

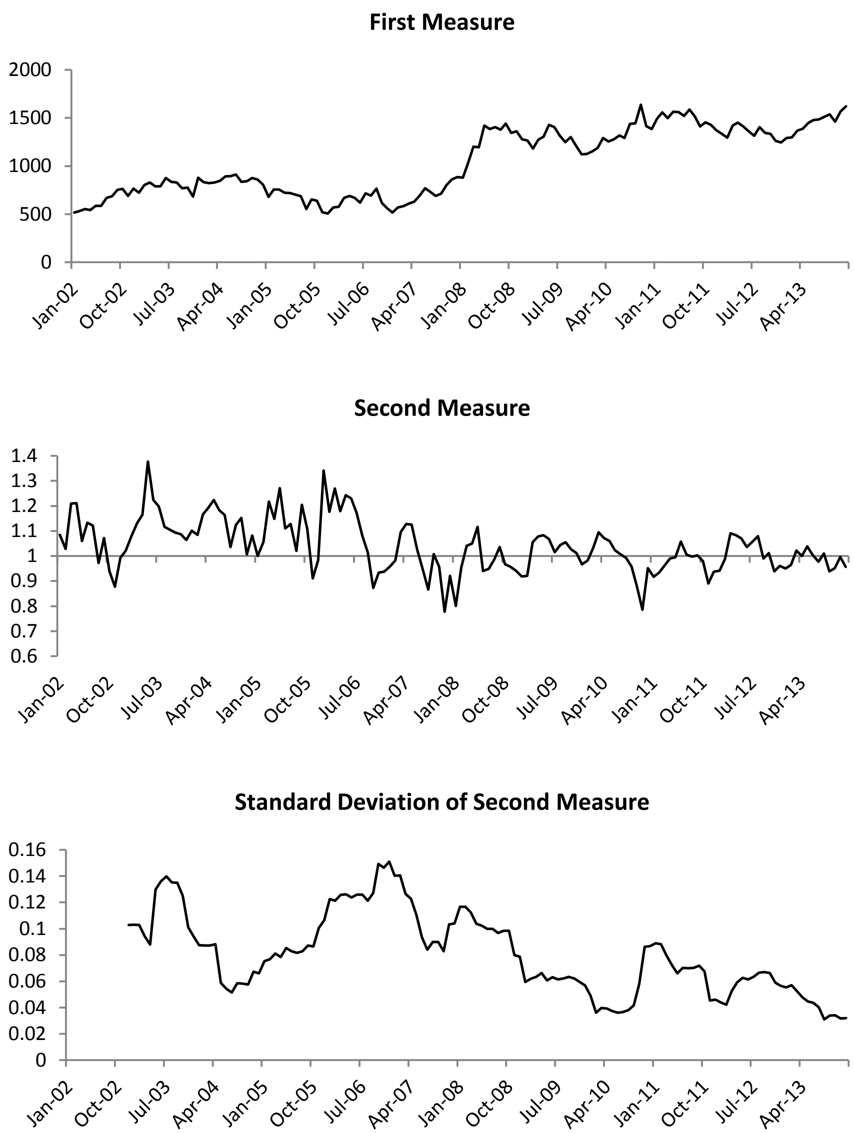


Figure 4.9. First Measure of Distance, Second Measure and its standard deviation with a rolling window of 12 months, from January 2002 to December 2013

5.3. Distance-based strategies

In a fundamental paper by Gatev et al. (2006), pairs trading is implemented over the period 1962 to 2002 in two steps. They first match stock pairs over a 12 month "formation period" and then trade them for the next 6 months during a "trading period." Hence, the result is equivalent to six independent desks trading the same strategy starting in consecutive months. The signals for beginning and ending a trade are based on the number of historical standard deviations between prices of the two stocks forming the pair – a trade is opened when prices are two standard deviations apart. Bianchi et al. (2009) find evidence of profitable pairs trading amongst 27 futures contracts across the energy, agriculturals and metals commodities markets over the period 1990 to 2007. Unlike the matching of stocks based solely on the historical co-movement of prices, as in Gatev et al. (2006), pairs in their study are only formed within their respective commodity sector – an agricultural commodity can only be paired with another agricultural, for example.

In order to illustrate the use of the first and second measures in trading, we introduce a simple trading strategy for the second period. In order to compare our results we show the results employing two different pairs trading strategies from the fundamental paper by Gatev et al. (2006).

In the first strategy, returns are calculated during the 12-month formation period and then traded thereafter based on the same pre-specified rule of Gatev et al. (2006), entering when prices are two standard deviations apart. The pre-specified rule for exiting the trade is when prices revert to their mean. This strategy is comparable to a buy and hold strategy, since no new formation periods are allowed. In the second strategy, unlike the first, the pair is traded for six months following the 12-month formation period and, as in Gatev et al. (2006), with the same pre-specified rules for entering and exiting the trades as in the first strategy. The final strategy uses our first measure of distance. The strategy is market neutral and consists of using the maxima and minima of the first measure, above and below the mean respectively, as opening trading signals and the crossing of the mean as the closing trading signal. The trades are executed in the first nearby Futures. Any of the other short maturity Future contracts could also be chosen as alternative contracts, as long as they have identical maturities and exhibit similar volatilities.

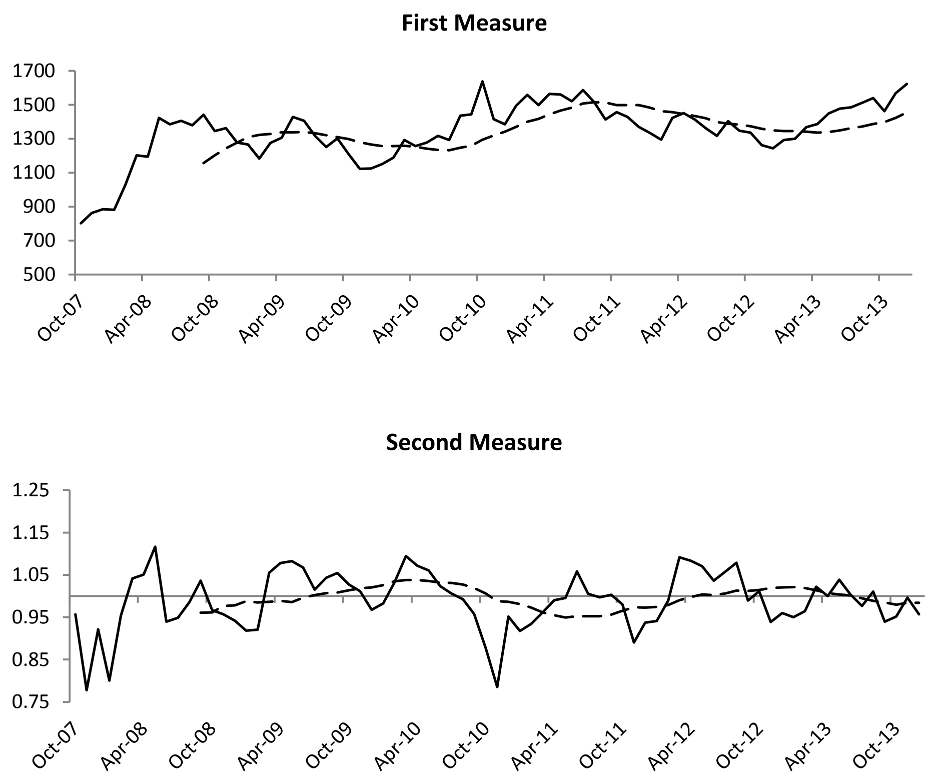


Figure 4.10. First and second measures of distance with their corresponding means calculated with a 12 month rolling window, from October 2007 to December 2013

We plot both measures of distance and their respective means using a rolling window (see Figure 4.10). First, we study the maxima above the mean in the first measure of distance. In a mean-reverting strategy, in agreement with the exhibited integration of the two markets, when we reach a maximum in the first measure, the expectation is that the distance will decrease in subsequent periods. This means taking a long position in the spread, i.e., long CME Live Cattle, short BMY Live Cattle (the spread CME Live Cattle – BMY Live Cattle is negative throughout the period). We have thirteen long trades, ten with positive returns and three with negative returns, with a total return of 105 per cent. Apart from the first two maxima at the beginning of the sample, when prices are still transitioning from the previous state to the new one, i.e., from a higher to a lower standard deviation in the second measure, only one other long trade shows a negative return. The single most profitable trade, with a 34 per cent return, is on the 29th of October 2010, which is also the global maximum. Secondly, we study the minima in the first measure of distance that are located below the mean. When a minimum is reached, the expectation is that the distance will increase in subsequent periods. This signals taking a short position in the spread. There are seven trades, four with positive returns and three with negative returns, making a total return of -11.7 per cent. Overall, the strategy is profitable with a 86 per cent return over 63 months (5.25 years), standard deviation of 13.16, and maximum drawdown of -21 per cent and a Sharpe Ratio of 5.07 (see Table 4.3). When we compare the results of the strategy using the first measure of distance (strategy 3) to the other two traditional pairs trading strategies (strategies 1 and 2), strategy 3 is clearly superior. Although it provides a higher number of trades, which would incur higher transaction costs, it has a much higher Sharpe Ratio, almost doubling that of strategy 2 and seven times higher than the Sharpe Ratio of strategy 1.

Table 4.3
Summary of results for three trading strategies.

Strategies:	**Strategy 1** Formation Period 12 months Trading Period Unlimited	**Strategy 2** Formation Period 12 months Trading Period 6 months	**Strategy 3** First Measure Of Distance
Number of Trades:			
Long Spread	2	3	13
Short Spread	0	2	7
Average Duration of Trades (in months)	11.5	8	5.15
Excess Returns:			
CME	0.28	0.17	0.90
BMY	-0.16	0.03	-0.04
Total	0.12	0.2	0.86
Distribution Statistics of Excess Returns:			
Mean	0.0204	0.0215	0.0242
Median	0.0195	0.0251	0.0250
Standard Dev	0.1208	0.0720	0.1316
Skewness	0.0069	-0.9629	0.2970
Kurtosis	-5.8119	2.0627	0.6823
Sharpe Ratio	0.72	2.7	5.07

To summarize this section, we find that the first measure of distance exhibits a change of level in 2007-2008, which coincides with our previous analysis of structural breaks, while the second measure shows a lower standard deviation in the latter period, supporting the existence of cointegrating spot prices. We have also shown that our trading strategy using the first measure of distance is clearly superior to other pairs trading strategies.

Furthermore, the first measure gives an indication of the direction of the spread, while the second measure allows us to evaluate the amount of additional information contained in the forward curves versus the first nearby. In this way, it may allow us to identify the points in time where this relationship was broken or changed. One could use this feature of the second measure in the development of new and old trading strategies and add an extra layer of information to the first measure.

6. Conclusion

In this Chapter, we investigate the live cattle market, a worthwhile subject at a time when a larger number of human beings, particularly in developing countries, finally have access to richer diets and meat. Analyzing the price trajectories of the first nearby contracts of the live cattle Futures traded in the US and Brazil, we find two periods, separated by a structural break in October 2007, when the relationship between US and Brazilian cattle markets greatly differs. In the first period, from January 2002 to September 2007, the US was a net importer of meat and Brazilian live cattle prices lead US Live Cattle prices. In the second period, from October 2007 to December 2013, the relationship becomes bidirectional and the variables cointegrated.

Our main contribution is the introduction of a novel approach that can be used to study the joint dynamics of the forward curves. We introduce two measures of distance between forward curves which allow us to take into consideration the information contained in the entirety of the forward curves. Moreover, we show that these measures present different characteristics in each period, supporting our previous structural breaks analysis and indicating that, in the second period, not only do the spot prices move together but also the whole forward curves.

Lastly, we use the property of integration of the two markets in the period 2007-2013 to devise a profitable strategy using the first measure of distance. We show the superiority of our strategy by comparing results to more traditional and well documented pairs trading strategies.

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Chapter 5. Conclusions

1. Final Remarks

This thesis is focused on the empirical examination of the spot and forward markets of agricultural commodities. Futures markets are very important, not only for companies that operate in the commodities arena to hedge their risk, but also for investors such as hedge funds and pension funds. However, for some commodities, as in the case of fertilizers, Futures markets are not developed and the only alternatives for investors to gain positive exposure are to take physical positions or buy equity of firms in that sector. This is in stark contrast to other agricultural commodities, such as corn, which enjoy highly liquid Futures markets. The study of the relationship between forward and spot prices is essential for both academics and practitioners. Investment decisions should take into account all information embedded in the forward curve, structural changes, and additional sensitivities or correlations between commodities.

In Chapter 1, we establish three classes of commodities that are of vital importance to food security on a global scale: fertilizers, which are becoming an asset class in its own right; grains, particularly corn and wheat; and cattle. All three commodities are closely linked. Fertilizers are vital for the successful growth and increased yields of corn and wheat. In turn, corn and wheat are essential for the nutrition of cattle and, therefore, also crucial in meeting the objectives for meat production. It is the changing price dynamics of these key commodities coupled with the issue of global food security that provides the motivation for our thesis and prompt several important research questions that have not yet been addressed in the literature. More specifically, what tools and trading strategies can be made available to a broad range of market participants - including farmers, policy makers, and investors.

Chapters 2, 3, and 4 address issues of food security and food price risk from a financial standpoint, primarily in terms of developing innovative investment and hedging strategies using the information embedded in Futures contracts, forward curves, and different measures of dispersion. All market participants need to be aware of the information available to them, in particular, from both the financial derivatives themselves as well as the fundamentals of the physical agricultural commodity markets in question, especially since commodities are generally priced by supply, demand and inventory. Hence, understanding their fundamentals (in our case, corn, wheat, fertilizers, and live cattle) is of vital importance for successful investment, which is why we have also included this type of discussion in each of our chapters.

2. Important Findings and Contributions to the Literature

The research presented in this thesis contributes to the existing literature on agricultural commodities in several ways. Firstly, we close a gap in the literature by presenting several topics that have never been explored before, including fertilizer markets, the use of the average of forward prices as a predictor of corn and wheat spot prices, and the relationship between cattle markets and measures of distance between forward curves. Secondly, in order to study these topics, we present innovative ways in which to analyze them. These new methodologies and tools are not only important for the academic community but also for other groups, such as industry participants, since they provide us with further insight and a whole new set of information that was not previously available. Lastly, this thesis contributes to the public discussion on the importance of agricultural commodities and the challenges we face to feed the world population in years to come.

Each chapter makes several important contributions to the literature. In Chapter 2, “Performance of publicly traded fertilizer-mining companies and their relationship to agricultural commodities and fertilizers,” we first conduct a structural break analysis, which has been conducted in commodity related studies including Worthington and Pahlavani (2006) and Wang and Tomek (2007) in order to account for important changes in the dynamic of commodity prices. Commodity prices can be influenced by macroeconomic factors, financial crises, or trade policies. The remarkable synchronicity of the breaks in corn and wheat price trajectories – corn and wheat account for the greatest use of fertilizer worldwide – is in agreement with the substitutability between these two commodities which are central in the production of bread, cereals, feedstock and human food. The fact that the break in the fertilizer index price trajectory took place some months after corn and wheat could reflect the delayed price increase of fertilizers decided by producing companies facing a rising demand from farmers worldwide in a search for better productivity in the next harvest. The price spike in fertilizers also made this commodity visible to investors.

We then investigate if investing in fertilizer-mining companies – given the absence of liquid Futures contracts – is a good way to hedge against agricultural commodity prices. We extend the literature on investing in commodity related company stocks (see, for example, Tufano, 1998; Blose and Shieh,1995) to fertilizers, a topic which has not yet been addressed. Using the CAPM framework, we show the purchase of shares of Mosaic, Agrium, Potash and other fertilizer-related companies was a very wise investment, especially when fertilizers first came to the attention of the agricultural finance world, with returns as high as 60% over the period 2004 to 2012. Hence, we exhibit the validity of investing capital in fertilizer mining companies, both from a market return perspective for individual or institutional investors. Lastly, we illustrate how pension funds and insurance companies wishing to hedge the inflation risk should include shares of fertilizer-mining companies in their portfolios since they exhibit significant sensitivities to the prices of agricultural commodities, which are a key component of inflation indexes.

Chapter 3 presents two important issues highly relevant for policymakers and regulators, since both provide better warning signals with regards to rising food prices. Firstly, we illustrate that, in the case of agricultural commodities, the coefficient of variation and the standard deviation of prices are more informative measures of uncertainty than the traditional “volatility” generally used in finance. Furthermore, we show that different types of participants may benefit from distinct measures of dispersion. For instance, since farmers are directly affected by price volatility, which can have a long term influence on producers and their production schedule, they should be most concerned with the standard deviation of prices. In contrast, government regulators and policymakers would benefit from using the coefficient of variation since it provides better intra-year information. We find that the coefficient of variation and the standard deviation of prices would have provided better warning signals with regards to rising food prices.

In the second part of Chapter 3, we turn our attention to spot price predictors for wheat and corn markets. In recent years, the agricultural commodities markets have greatly changed and, in our opinion, a re-examination of forward curve prediction is highly relevant, not just in the REH framework but also in terms of the predictive power of Futures contracts at several lags and also using information from several contracts to predict future spot price. First, we test the relationship between spot and forward prices in the REH framework using log prices of Futures daily data for corn and wheat. In keeping with previous findings (for example, see Reeve and Vigfussion, 2011) we detect an important effect on the predictive power of the forward prices as the contracts become closer to expiry, in general, the predictive power of the forward prices is greatly reduced. Our results show that the predictive power of individual forward contracts seems to be most negatively impacted at times of planting, heading and harvesting. Leaving aside the framework of the REH, we proceed to find the best, if any, lag of prediction for each nearby Futures contract. In contrast to the REH, which establishes that each nearby would have predictive power only at their respective maturity, we look for the lag that has the highest predictive power – the "optimal lag". More specifically, we define the "theoretical optimal lag" as the lag with the most predictive power obtained from the interpolated nearby Future contracts (since, in general, Futures contract maturities in agricultural commodities markets are unequally spaced in time). In the case of CBOT Corn, we observe that the "theoretical optimal lags" are always lower than the corresponding maturity. Lower optimal lags indicate that the best predictions correspond to future spot prices that happen earlier. In contrast, in the case of CBOT Wheat, the "theoretical optimal lags" from F4 to F11 are higher, i.e. individual Future contracts offer a better prediction of later future spot prices. This could be explained by the fact that wheat production and prices are less dependent on a single country of production while the corn market is dominated by US domestic supply-demand forces.

Finally, we show that the geometric average of the forward curve introduced in Borovkova and Geman (2006) performs better as a predictor for corn and wheat spot prices than individual maturities. We compute $\bar{F}$ as the average of maturities across twelve months. This quantity has the merit of being less volatile than the noisy spot price, is always observable, and provides several advantages over the use of forward prices of individual maturities. Each $\bar{F}$ captures the difference in range of prediction found in the nearby Futures at their theoretical optimal lags, for instance, the $\bar{F}$ of wheat captures the fact that the best predictions are at later lags. Hence, in the case of wheat, the optimal lags of $\bar{F}$ are 9 and 11 respectively for each construction of $\bar{F}$, which are much higher than those of corn, with optimal lags of 6 and 9 respectively. We compare the average value of all liquid forward contracts with several VECM models and individual maturities and we find that the average value of forward contracts provides several advantages over the use of forward prices of individual maturities, in particular during the periods of planting, heading, and harvesting, when individual maturities have a much lower predictive power. These facts show the reliability of $\bar{F}$ throughout time and that $\bar{F}$ a better predictor than individual maturities for both wheat and corn markets.

In Chapter 4, we look at the live cattle market, an agricultural market which is growing in importance. Like fertilizers, cattle has essentially been unstudied in the financial literature, particularly the relationship between the two most important cattle markets worldwide: the US and Brazil. Hence, an understanding of the relationship between spot and forward prices in these two regions is of the utmost relevance, especially now when a larger number of humans, particularly from developing countries, can afford to include meat in their diets.

Following an overview of the physical live cattle markets and establishing the commodity as a semi-storable one, we conduct a structural breaks analysis, finding that the structural breaks for US and Brazil live cattle prices – October

2010 and June 2007, respectively - represent points in time when prices began to move in a steep uptrend, and when both countries experienced increases in levels of exports. To study the relationship between the two markets, we carry out Granger causality and cointegration analysis, revealing that while there is a causal relationship in the first period, there exists a cointegrating relationship in the second period, which shows the growing relationship between US and Brazilian live cattle in more recent years, reflecting the rapid development of the live cattle markets in both regions.

Our main contribution to the academic literature in this chapter, after establishing the relationship of US and Brazilian live cattle in previous sections, is the introduction of two measures of distance between forward curves, which allow us to take into consideration the information contained in the entirety of the forward curves for live cattle. We also devise a profitable strategy for Brazilian and U.S. live cattle markets and compare it to strategies from existing literature related to trading pairs of Futures contracts. We show that our strategy clearly outperforms the others, since it takes into account all information offered by the forward curves, and not just spot prices.

3. Directions for Further Research

There are several interesting avenues for further research. In the specific case of agricultural commodities, it would be interesting to extend the analysis of the average forward curve as a predictor of spot prices to other agricultural commodities with different degrees of liquidity in their Futures markets. Also, it could be interesting to extend the use of the new measures of distance proposed in this thesis, from the analysis of spatial relationships to inter-commodity relationships. More generally, in the wider field of commodities, the new measures of distance could be used to explore relationships among energy commodities or metals.

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