An Empirical Study of Backwardation in Commodity Markets (1990-2012), based on the Theory of Storage and the Convenience Yield

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“What is a cynic? A man who knows the price of everything and the value of nothing. And a sentimentalist, (...), is a man who sees an absurd value in everything, and doesn't know the market place of any single thing.”

Oscar Wilde, Lady Windermere’s Fan (1892)

Preface

This thesis concludes my Master of Science degree in Business Administration at the UMB (The Norwegian University of Life Sciences) School of Economics and Business, with a major in finance. The research process has been carried out from January to May 2013.

First, I wish to express my sincere gratitude to my supervisor professor Ole Gjølberg for several important comments and guidance in the process of writing this thesis.

I am also grateful to My Vuong for reading my thesis, giving useful comments on structure, style and spelling.

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Abstract

In this thesis, I examine the variation in the net cost of storage for five different commodities by using an ANCOVA model, based on arguments derived from the theory of storage. The net cost of storage is in this thesis defined as the interest adjusted relative basis, between the spot price and a futures price. The variation in this variable is particularly interesting, as it is assumed to be highly correlated with the convenience yield. Furthermore, I conduct a test for a structural break in the model after 1999, to see whether the increase of speculative positions in commodity markets have influenced the valuation of the convenience yield. This thesis also includes a discussion on the possible behavioral and economical incentives that different market participators might have to store commodities at a negative return.

The commodities included in this study are CBOT corn, CBOT soybeans, CBOT wheat, NYMEX WTI and COMEX copper. The data set consists of monthly observations from March 1990 to December 2012[1].

This paper contributes to the field of commodity analysis by presenting empirical proof concerning the validity of the theory of storage. As predicted by the theory, I find that changes in the inventory level clearly affects the relationship between the spot price and the futures price in commodity markets. The inventory's effect on the net cost of storage is also found to be affected by seasonal cycles in the commodity's supply. Further, I also present results indicating that the total composition of market participants influences the behavior of the convenience yield.

My thesis offers an interesting approach on commodity markets, relevant for commodity hedgers, speculators and others with a particular interest in commodity prices.

[1] Copper data was only available from October 2001 to December 2012.

Sammendrag

Forståelse for dynamikken til "convenience yield" er essensielt når det kommer til prising av futureskontrakter. Derav er også variablen interessant med tanke på beslutninger knyttet til hedging beslutninger og predikering av priser. I denne oppaven benytter jeg en ANCOVA, modell, utledet fra "the theory of storage", for å studere variasjon i netto lagerkostnaden til fem ulike råvarer. Netto lagerkostnad er her definert som den rentejusterte relative basisen mellom spotpris og en futurespris. Variasjon i denne variabelen er spesielt interessant på grunn av dens høye korrelasjon med "convenience yield". Videre tester jeg for strukturelle brudd i modellen etter 1999, for å undersøke om økningen i spekulative posisjoner i råvaremarkeder har påvirket markedets vurdering av "convenience yield". Oppgaven inkluderer også en diskusjon relatert til hvilke adferdsbaserte og økonomiske insentiver markedsaktører har til å lagre råvarer med et forventet tap.

Råvarene som er inkludert i studiet er CBOT mais, CBOT soyabønner, CBOT hvete, NYMEX WTI (råolje) og COMEX kobber. Datasettet består av månedlige observasjoner fra mars 1990 til desember 2012[2].

En regresjonsanalyse viser at den benyttede modellen forklarer opptil 61% av variasjonen i netto lagerkostnadene. Dette bekrefter at argumentene utledet fra "the theory of storage" innehar en empirisk verdi som forklarer hvordan markedet estimerer verdien av en råvare. Jeg finner også statistiske bevis på sesongvariasjon i netto lagerkostnad for mais, hvete og soyabønner.

Fra testen for strukturelle brudd etter 1999 fremkommer både grafiske og statistiske bevis for at det har forekommet en endring i markedets verdivurdering av "convenience yield" for mais og hvete. Disse endringen samsvarer med en mer spekualtiv pristilnærming, hvorav det gis mindre vekt til fundmentale kriterier, som for eksempel lagernivå.

[2] Kobberdata var kun tilgjengelig for perioden oktober 2001 til desember 2012.

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1 Introduction

To explain how and why the spread between the spot price and the futures price changes, it is critical to understand how the underlying mechanisms of commodity pricing work. The theory of storage offers an explanation to this price spread, based on the availability of the commodity. This paper examines the theory of storage's topicality in five different markets for storable commodities, using data from 1990-2012. The assumed spot-futures parity is especially interesting regarding storable commodities, as physical storage does not yield any derived payoff in direct monetary terms (Fabozzi, Fuss, & Kaiser, 2008).

According to the efficient market hypothesis and the theory of storage, the expected future price of a storable commodity should be equal to the current spot price, plus capital costs and storage costs (Kaldor, 1939). This indicates that the price of futures contracts normally should top the current spot prices by an amount equal to the total cost of carrying. Still, commodity markets are known to frequently experience the opposite situation, offering a negative return to storage, often referred to as backwardation or inverted market prices.

Inverted market prices are both theoretically and practically interesting because it seemingly violates the well-established non arbitrage argument. In backwardation, an inventory holder can theoretically earn a risk free profit by selling out stocks and then use the money to buy a corresponding futures contract for less than the amount received from the first sale. This supplies the market with a seemingly free lunch opportunity, through a reversed cash and carry arbitrage condition.

One of the most traditional ideas attempting to rationalize this phenomenon is *the theory of normal backwardation*, first presented by John M. Keynes (1930). Keynes' theory is mainly based upon assumptions regarding the net hedging pressure and a risk premium. The basic idea is that when net hedging pressure is short, a risk premium is paid by the producers to compensate speculators, working as a discount on the futures price, making it less than the market spot price.

An alternative explanation comes from Kaldor (1939), Working (1948) and Brennan (1959), and *the theory of storage*. This theory explains backwardation in commodity markets by including a term known as the convenience yield into the spot-futures parity model.

Economically, the convenience yield can be interpreted as the monetary value of benefits achieved form holding a commodity in its physical form. Thus, at times when the magnitude of the convenience yield exceeds the total cost of holding the physical commodity, markets will go into backwardation, as inventory holders estimated a higher value for their asset. The convenience yield is assumed to be closely linked to storage levels and peoples fear of stock-outs, indicating that the convenience yield is large in periods of scarcity, and close to or equal to zero in times with surplus.

In this thesis, backwardation in storable commodities is examined through framework derived from the theory of storage, assuming the existence of a convenience yield. The analysis is carried out on the United States (U.S.) market for five storable commodities, covering a time period from January 1990 to December 2012. The five commodities included in the thesis are CBOT corn, CBOT soybeans, CBOT wheat, NYME WTI curd oil and COMEX copper. These commodities are expected to hold different properties regarding supply, demand and seasonal fluctuations, thus making it possible to give an answer to the question whether the behavior of the convenience yield depends on any of these various characteristics.

The model used to examine the convenience yield will be based on three of the classical arguments following from the theory of storage. These arguments are defined as the inventory level, spot price volatility and capital costs. Since the convenience yield is not an observable statistic, the interest adjusted basis will be used as a proxy variable. Similar models have been tested before, proving that the relationships proposed by the theory of storage is indeed valid (Carbonez, Nguyen, & Sercu, 2010; Duan & Lin, 2010; Symeonidis, Prokopczuk, Brooks, & Lazar, 2012).

The papers cited above focus very little on the term structure of the convenience yield, and how it is potentially affected by business/harvest cycles. Futures contracts with different maturities can represent different storage scenarios, due to seasonality in supply. Thus, spot-futures spreads, calculated by using futures contracts with different length to maturity, are expected to react differently on a change in the storage level. This paper differs from former studies by focusing on how the market estimates the value of convenience yields derived from futures contracts with different time to delivery.

The model also includes two qualitative binary variables, each representing a unique market state. The variables measure the effect of how the monthly inventory is seen in relation to its five years average, and the effect of the commercial net hedging pressure.

The model used in this thesis are not meant to forecast the convenience yield, but rather illuminate how the arguments derived from the theory of storage affects the variation in the price basis, assuming the existence of a convenience yield.

Revoredo (2000) emphasizes that the existence of a convenience yield depends on the composition of market participants. After the Commodity Futures Modernization act became operative in year 2000, the amount of speculative positions in the commodity futures markets increased significantly. A speculator is a market participant with no real use for the physical commodity, and should thereby not be affected by a convenience yield. To examine whether this increase in speculative positions influenced the valuation of the convenience yield, I include a test for structural breaks in variables after 1999. The expectation is that a more speculative pricing of commodities, should make the effect of market fundamentals like the inventory level to decrease.

This dissertation is divided into eight chapters. Following this introduction, chapter 2 contains a short primer on the characteristics of commodity assets and the general dynamics of commodity markets. Chapter 3 presents a review of the most relevant literature concerning backwardation in commodity markets, and the convenience yield. Chapter 4 includes the research questions I will try to answer through this thesis. Chapter 5 explains the data and method used in the statistical analysis. The results are presented in Chapter 6. Chapter 7 and 8 contains a discussion of the findings, and conclusive answers to the research questions, respectively.

2 Commodities

2.1 Characteristics of Commodity assets

Commodity assets are known to differ from other more classical assets groups like stocks and obligations. Robert J. Greer (1997), presents three master classes of assets in form of capital assets, store of value assets, and consumable or transferable assets. Equity capital like stocks and obligations are considered as capital assets, while real estate can be given as an example of a store to value asset. This naturally leaves commodities as a consumable or transferable asset.

Two of the most peculiar attributes that distinguish commodities from regular capital assets are the lack of derived monetary earnings like dividends or interests and the limited supply of the physical good. These two attributes indicates that commodities cannot be considered as a pure asset, and pricing models based on future cash flows become less useful (Markert & Zimmermann, 2008). Due to this, a commodity's value is rather assumed to be derived from the commodity's intrinsic value, which are based on factors like scarcity, range of substitutes, and supply and demand relations (Fabozzi et al., 2008).

Other important features characterizing commodities are the degree of storability, durability and renewability. These attributes varies between different commodity classes as well, and commodities are thereby normally divided into subcategories, based on their characteristics and range of use. In the first level of subcategories, commodities are often described as either hard or soft. Energy and metal based commodities are usually defined as hard commodities, while live stock and agricultural commodities are referred to as soft. Hard commodities are normally considered to be nonrenewable, and supply thereby depends strongly on the extraction rate of the producers. Soft commodities like grains are on the other hand considered renewable, since they can be planted, harvested and planted again next year, leading to a volatile deterministic supply pattern (Fabozzi et al., 2008).

Seasonality is also considered as an important characteristic, distinguishing commodity assets from other asset groups (Back, Prokopczuk, & Rudolf, 2013; Duan & Lin, 2010; Fama & French, 1987). Seasonality is known to vary between different commodity classes. For example, the supply of grains is affected by both harvesting cycles and weather conditions. The supply is often more stable for energy commodities, but in this class, consumption often varies with out-door temperatures. Metals are on the other hand known to hold no significant evidence of any particular seasonality in neither supply nor demand (Fama & French, 1987; Hernandez & Torero, 2010).

2.2 The dynamics of commodity markets

There are many different ways to get financially exposed to commodities. Producers get naturally exposed through their production output, while consumers and investors can choose between buying the physical commodity in the spot market or to buy different derivatives reflecting an underlying commodity price. A third way to obtain exposure is through the purchase of shares in companies with revenue that depends strongly on a certain commodity price. (Fabozzi et al., 2008).

One of the most common ways of getting exposed to commodities for the non-producing side is through futures contracts. A futures contract is a bilateral agreement on either making or taking delivery of a certain asset, upon an agreed price paid at delivery some settled time in the future[3]. Spot and futures prices that are based on the same underlying asset, are thereby expected to reflect much of the same market information, making the movements in the two prices more or less similar (French, 1986; Malkiel, 2003; Timmermann & Granger, 2004).

In conjunction with this, futures price are assumed to represent the expected future spot price of the commodity. Due to this assumption, there has been conducted much effort in testing for lead-lag relations between spot and futures prices. One example is Hernandez and Toro (2010), who finds that in agricultural markets, changes in futures prices lead to changes in spot prices more often than the reversed, thereby confirming the assumption. Thus, another supplementing role of futures prices is the forecasting ability of the expected future spot price.

The commodity futures market is generally divided between three different groups of market participants. The first two groups can be defined as commercial consumers and producers who wish to secure against volatility in future prices by entering into binding contracts. This activity is often referred to as hedging, and is frequently used to lock in incoming or outgoing future cash flows, thus minimizing the risk associated with volatile prices. In most markets

[3] For a more detailed explanation on futures contracts see e.g. Options, futures and other derivatives by John C. Hull (2012) or visit www.cme.com.

the number of these commercial buyers and sellers are not in equilibrium, generating the need for a third participant, namely the speculators.

A speculator's job is to take up the redundant market positions, depending on the net hedging pressure[4] (Fabozzi et al., 2008). The speculator's economic incentive is assumed to come from a risk premium paid by either the producers or the consumers. For example, in a market where the commercial net hedging pressure is short, producers will pay speculators a premium, or more rightfully sell futures contracts at a discounted price, reflecting the speculators required rate of return on the futures contract.

The spread between the spot and the futures price is an important magnitude regarding hedging decisions and whether to sell or by a respective commodity. This spread can hold both positive and negative values.

A positive price spread, indicating that the futures price exceeds the spot price, is usually referred to as *contango*. Theoretically this can be considered to be the natural state of a commodity market in equilibrium, since the futures price is expected to reflect both storage costs and the loss of interests from holding the physical commodity. The contango spread is constrained by the cash and carry arbitrage assumption, saying that futures prices cannot top spot prices by more than the total price of carrying. If a futures contract could be sold to a higher price than the total acquiring and storage cost of the physical commodity an arbitrage opportunity would occur. Opportunities for risk free earnings like this are expected to disappear immediately as they arise, creating an upper constrain on the futures price (Fabozzi et al., 2008).

In the opposite case, i.e. when spot prices top futures prices causing a negative price spread, the market is said to be in *backwardation,* or to hold inverse carrying charges. Despite its violation of the non arbitrage argument, this market situation occurs frequently and often systematically in many commodity markets (Yoon & Brorsen, 2002).

[4] Net hedging pressure is defined as the difference between commercial short positions and commercial long positions in futures contracts.

Contrary to the positive basis, a negative spread is not exposed to any constrains on its magnitude, apparently offering a reversed cash and carry arbitrage opportunity. This phenomenon has thereby given motivation to a large body of work, aiming to explain backwardation and the underlying market psychology found in various commodity markets. Some of these theories will be presented in the next chapter.

3 Literature on Backwardation and Convenience yield

3.1 The theory of normal backwardation

One of the most classical explanations to inverted market prices is *the theory of normal backwardation*, first proposed by the British economist John M. Keynes (1930). Keynes predicted backwardation to be the normal market condition between the spot price and the futures price, hence creating a stable negative price spread. His theory explains backwardation by assuming that the net hedging pressure is naturally short, and thereby creates an excess demand for buyers of futures contracts (Keynes 1930). The gap between long and short positions is filled by speculators who demands remuneration for the risk associated with their activity, making the futures price lower than spot price (Lautier, 2005). This market condition is according to Keynes the normal state in most commodity markets, thus referring to it as normal backwardation.

The expectation of a higher future spot price relative to the futures price is a speculator's main incentive to take up a position in a futures contract. Following Kaldor's (1939) algebraic reproduction of Keynes' theory of normal backwardation, this relationship can be written as

$$E(S_T) - S_t = i + c + r \qquad (1)$$

$$F_{t,T} - S_t = i + c \qquad (2)$$

$$F_{t,T} = E(S_T) - r \qquad (3).$$

In the equations above i, c, and r refers to the marginal values of the interest rate, cost of carrying and the risk premium, respectively. Further on, S_t, $E(S_T)$ and $F_{t,T}$ are the spot price at time t, the expected spot price at time T and the price of a futures contract at time t with maturity at time T, respectively. A speculator's implied return is in this case the expected price of the commodity at time T, minus the price of the futures contract, bought at time t, giving $E_T(S) - F_{t,T} = r$. The risk premium can in this case be regarded as the minimum rate of return set by the speculator.

In this case, the futures price will equal the expected future spot price only when the risk premium is equal to zero, that is when supply and demand is balanced. When speculative stocks equal zero, a steady price is achieved and $S_t = E_T(S)$. These conditions gives $F_{t,T} = S_t - r$, leading to $F_{t,T} < S_t$, i.e. backwardation (Brennan, 1958).

Still, in some commodity markets it has been more natural to talk about normal contango rather than normal backwardation (Symeonidis et al., 2012). This is an empirical fact also pointed out by Kaldor (1939) and Working (1949). Also, the commercial net hedging pressure has through time proven to be mainly long in several commodity markets that still experience backwardation (Fishe & Smith, 2010).

This signifies that a risk premium linked to the lack of commercial long hedgers cannot always explain backwardation, at least not by following Keynes' argumentation. The main reason is that an excess quantity of long hedgers intuitively should reverse the relationship regarding the risk premium, making the futures contract more expensive than the spot price, thereby creating a state of contango. The same idea is also supported in a working paper by Fishe and Smith (2010). In this regard, Keynes' theory of normal backwardation can seem a bit incomplete concerning today's commodity markets, necessitating the need for additional explanations.

3.2 The theory of storage

The theory of storage offers an alternative explanation to inverted market prices. While the theory of normal backwardation is mainly centered on the balance between trading commitments and a risk premium, the theory of storage is based upon storage levels and the motivation of holding physical inventory under inverted market conditions.

An essential part in the theory of storage was the introduction of a variable called the convenience yield. As a concept, the convenience yield was first introduced by Nicolas Kaldor in *Speculation and economic stability* from 1939. Kaldor claimed that all goods, measured in terms of themselves, posses a yield, caused by the implied utility associated with holding physical stocks, thereby allowing production and delivery to become more robust against shocks occurring in supply and demand.

By adding this yield to the equation system found in equation 1-3, Kaldor came up with the following relation,

$$F_{t,T} - S_t = i + r + c - y = m \tag{4}$$

In equation 4, y denotes the marginal convenience yield and m the net marginal cost of storage (Kaldor, 1939). Rest of the notation is explained through equation 1-3. The dynamics of equation 4 is rather straight forward. During backwardation, the value of y must be greater than the total cost of storing, i.e. ($y > (i+r+c)$). The implied value of holding physical stock is thereby higher than the total cost of storing, and the net marginal cost of storage becomes negative.

The idea of a convenience yield was later picked up by Holbrook Working (1948, 1949), who proposed evidence that negativity in the basis of commodities tends to be correlated with the storage level. Through a study of different grain markets in the U.S., covering the period from 1896 to 1932, Working proved that spot prices tend to top futures prices during times with low inventories. This relationship has also been proven to be present in today's modern commodity markets as well (Carter & Giha, 2007; Joseph, Irwin, & Garcia, 2011).

Michael J. Brennan (1958) made further examination of the link between inverted market prices and the storage level. Brennan estimated the net marginal cost of storage by employing a model based on the total cost of carrying, the convenience yield and a risk factor related to risk aversion, assuming that all factors where functions of the storage level. Algebraically, Brennan calculated the net marginal cost of storage in the same way as in equation 4. Note that Brennan assumed the net marginal storage cost to be affected by a risk aversion factor rather than a monetary risk premium. The properties of the variables and how they are affected by the inventory levels can be explained based on the graphs found in figure 1.

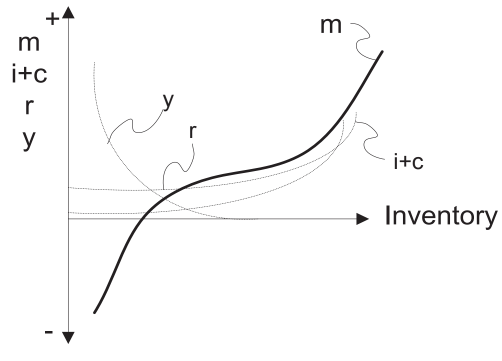

Figure 1: Marginal Cost of Storage

Figure 1 is a reproduction of the one used by Brennan, explaining the behavior of the different variables in the net cost of storage model found in equation 4. Brennan assumed that the marginal cost of storage (i+c), is stable until a certain level of inventory, where it starts to increase exponentially. This would be due to the high initial cost of building additional storage when the total storage capacity reaches zero.

A similar prediction is made regarding the risk factor. Brennan assumed that the financial loss caused by a reduction in the price would be an increasing function of the storage level. This type of risk is also one of the main reasons why many firms choose to buy commodity futures in the first place, since physical holdings often are associated with a higher risk.

Lastly, Brennan saw the marginal convenience yield as a decreasing function of the storage level, finally reaching zero for some high amount of storage. All together these three variables give the familiar cubic curve for net storage costs, denoted *m* in figure 1. This curve is also known as the *Working curve,* since its empirical existence was first proven through the work of Holbrook Working.

The curve signifies how the net cost of storage turns negative during periods with low inventory levels, due to an increase in the convenience yield. As the total inventory of a commodity rarely reaches a zero level, this also indicates that some market agents are storing commodities despite the expectations of a negative return.

Still, regardless of its theoretical attractiveness and empirical confirmation, the theory of storage has been subjected to criticism. The theory has been subjected to criticism, for instance by taking the convenience yield variable for granted, using it as a residual without explaining any of its real underlying nature.

The empirical value of the Working curve has also been questioned on behalf of possible measurement errors in Working's data. This argumentation is mainly based on the fact that Working used aggregated data from a time period where grain prices could differ significantly depending on geographical location (Carter & Giha, 2007). Brennan, Williams and Wright (1997), proposed that if the price spread is properly measured and compared with its geographically corresponding inventory, no stocks would be held during backwardation. Still, these results are somewhat mixed, as Carter and Giha (2007) and Joseph, Irwin and Garcia

(2011) found evidence that the relationship described by Working is valid, also when tested with local market data.

3.3 Explaining the Convenience yield

The modern textbook model used to calculate the convenience yield, offers a similar approach as the one found in equation 4. Instead of using marginal terms like Brennan, the modern approach usually make use of continuously proportional values as arguments (Fabozzi et al. 2008; Hull 2012). Algebraically, a futures pricing model based on the existence of a convenience yield can be written as,

$$F_{t,T} = S_t e^{(i+c-y)\tau} \tag{5}$$

For simplicity, the variable representing the risk aversion in equation 4 is not included, indicating that this is a risk neutral pricing model. The time factor $\tau = (T - t)$ is the time spread between time t and the maturity date of the futures contract, equal to time T. The rest of the notation is similar to equation 1-4. By assuming that storage cost is a fairly stable proportion of the spot price, variation between $F_{t,T}$ and S_t will mainly be caused by changes in the interest rate and the convenience yield (Dincerler, Khoker, & Simin, 2005).

By putting the expression $(i + c - y)\tau = \delta$ and assume that i and c are strictly positive, the convenience yield's impact on the basis can be shown through some standard algebraic maneuvers.

A positive δ $(i+c > y)$, leads to

$$F_{t,T} = S_t e^{\delta} \rightarrow F_{t,T} > S_t.$$

This indicates that the cost of storage *(i+c)* exceeds the convenience of holding the physical commodity, ($y < (i + c)$), generating a state of contango. In the case of a negative δ $(i+c < y)$, resulting in

$$F_{t,T} = S_t e^{-\delta} = \frac{S_t}{e^{\delta}} \rightarrow F_{t,T} < S_t,$$

y must be greater than the total cost of storage making $y > (i + c)$, due to the positive constrain placed on the interest rate and the storage cost. This creates a state of backwardation. On behalf of this argumentation, inverted price relations occur as a result of an increase in the convenience yield.

Working (1949) and Brennan (1958) proved that variation in the basis of a certain commodity is closely linked to its storage level. Given the assumption of a stable and strictly positive storage costs, this also creates a link between the convenience yield and the storage level. Dincerler, Khoker and Simin (2005) tested this link by using the interest adjusted relative basis[5] as a proxy for the convenience yield. By regressing this proxy on inventory levels for crude oil, natural gas, gold and copper, they found that inventory levels explains 17-42 percent of the variation in the convenience yield for crude oil and natural gas, 4-18 percent for copper, and 2-3 percent for gold.

The results posted by Dincerler et.al (2005) illuminates how seasonally based fluctuations in supply and demand can affect the convenience yield. The demand for the two energy commodities are assumed to be affected by seasonal factors, and are thereby expected to be more frequently exposed to shocks, compared to the metal based commodities (Back et al., 2013). These shocks could make the total inventory level considering these two commodities, relatively much lower at some point through the year, causing the convenience yield to rise more sharply. This result indicates that the relationship between storage levels and the convenience yield is stronger regarding commodities that are subjected to seasonally in supply or demand.

Carbonez, Nguyen and Sercu (2010) test the effect of the storage level on the convenience yield, calculated as the cost adjusted basis, for wheat, corn and oats. They find strong results of a significant relationship between the convenience yield and the inventory level for all three commodities. A similar result is suggested by Symeonidis et.al (2012), as they test the effect of the inventory level on 21 different commodities.

[5] The interest adjusted basis was in this case defined as $\frac{F_{t,T}-S_t}{S_t} - i$, where $F_{t,T}$, S_t, and i, is the futures price, the spot price and the interest rate, respectively.

Paul Samuelson (1965) points out how volatility in the spot and futures price can be seen in relation to market backwardation. Samuelson explains how the volatility in the two prices tends to be equally low when inventories are high, but that the volatility in the spot price usually increase more than the volatility in the futures price when inventories are low (Samuelson, 1965).

The same market dynamic is also explained by Robert Pindyck (2001). He suggests that increasing price volatility is often a result of an increase in net demand, defined as the difference between demand and supply. He also explains how low inventory levels more often are caused by a decrease in supply rather than increase in demand. When supply goes down the net demand usually increase, causing more volatility in the spot price, eventually leading the market into backwardation.

Econometrical models measuring the effect of both inventory levels and price volatility have been successfully tested by Duan and Lin (2010) . More specifically, their model includes the logarithmic inventory level, the covariance between two futures contracts, and the interest rate[6]. The convenience yield was calculated through a Black and Scholes option pricing model. Through this model, Duan and Lin managed to explain up to 98% of the month specific variation in the convenience yield for crude oil (Brent and WTI), CBOT corn and CBOT soybeans. They find both the inventory term and the covariance term to be highly significant for all four commodities (Lin & Duan 2006; Duan & Lin 2010).

3.4 The Convenience Yield and Behavioral Economics

Much of the research conducted on behalf of the theory of storage has been based on models testing quantitative relations between the convenience yield and various explanatory variables. The theories and findings cited above offers important insight considering how the convenience yield behaves, but few of the articles elaborates on the psychological factors that seemingly lead to the irrational behavior of storing inventory under inverted pricing conditions.

[6] $y_{t,T} = \beta_0 + \beta_1 \log(I_{t-1}) + \beta_2 \sigma_{pt}^2 + \beta_3 i_{ft} + \varepsilon_t$. $y_{t,T}$ = convenience yield, $\log(I_{t-1})$= log of inventory levels, σ^2 = volatility between two futures contracts, i_{ft}=the risk free interest rate and ε_t= the residual term.

One exception is Yoon and Brorsen (2002), who discuss why some people choose to store commodities despite the expectation of negative returns. By referring to topics from the field of behavioral economics, they find three theoretical concepts offering possible answers to this question. The concepts used by Yoon and Brorsen are *anchoring*, *overconfidence* and *regret* (Yoon & Brorsen, 2002).

These concepts are closely linked to Daniel Kahneman and Amos Tversky's much cited *prospect theory* (Kahneman & Tversky, 1979). Prospect theory was developed as an alternative to the well established *expected utility theory*, and is more focused around actual behavior rather than optimal decisions.

As storing of physical commodities during backwardation is theoretically inconsistent with optimal decision theory based on expected utility, prospect theory might hold some possible answers to why some market participants choose to store their inventory, despite a negative return to storage. This topic will be further elaborated in chapter 7.

4 Research Questions and Hypotheses

This paper seeks to explain variation in the convenience yield, based on a theoretical approach motivated by the theory of storage. The convenience yield will be calculated as the net cost of storage between the spot price and several distant futures prices[7].

It will also include a statement on whether an increase in speculative positions in the commodity market for corn, soybeans, wheat, WTI and copper after 1999 have affected the convenience yield's behavior.

In addition, a discussion on what behavioral and economical reasons market agents have to store commodities under inverted market conditions will be conducted.

In this relation three research questions are proposed:

> *1) Does the theory of storage offer any explanation to movements in the price spread between the spot price and the futures price, in the U.S. market for corn, soybeans, wheat, WTI and copper (1990-2012)?*
>
> *2) Did the increase in speculative positions after 1999 affect the behavior of the convenience yield for corn, soybeans, wheat, WTI and copper?*
>
> *3) How can the convenience yield be related to behavioral and economical reasons to store commodities during times with negative return to storage?*

To answer the first research question the following hypotheses will be tested:

H 1.1) The inventory level is positively correlated with the net cost of storage.

The inventory's influence on the net cost of storage is the fundamental principal in the theory of storage. As explained in the literature review, negative returns to storage are expected to occur in times of low inventory levels. In this regard, the hypothesis states that the inventory level affects the net cost of storage positively.

[7] To read the expectations of the hypothesis correctly it is important to remember that the net cost of storage is a decreasing function of the convenience yield.

H 1.2) Spot price volatility is negatively correlated with the net cost of storage.

The spot price volatility is mainly included as an additional control variable. The variable is not directly related to the theory of storage, but has proven to be a significant variable in explaining the net cost of storage in earlier studies. This hypothesis states that the net cost of storage will decline in the case of an increase in the spot price volatility, thus offering a negative correlation.

H 1.3) The inventory's influence on the net cost of storage is affected by business/harvesting cycles.

The theory of storage suggests that people's fear of stock outs are the main cause for negative values in the net cost of storage. In this manner, a commodity's particular business cycle should affect the storage level's influence on the net cost of storage. This hypothesis accounts especially for agricultural commodities, given that the net cost of storage associated with a futures contract that matures after the next harvest session, should not be significantly correlated with the present inventory level.

To answer the second research question the following hypothesis will be tested:

H 2.1) There have been a structural break in the variables explaining the net cost of storage after 1999.

A speculator is assumed to be less, or not at all affected by low inventories since they have no real interest for the physical commodity. Thus, a speculator's valuation of a commodity's monetary value should not contain a convenience yield. Assuming an increase in speculative positions in commodity markets over the last decade, this should have caused a structural break in the inventory variable after 1999.

The third and last research question will not be tested by a hypothesis, but rather answered through a discussion on how theoretical concepts from the field of behavioral economics can explain the market agents' behavior during inverted markets.

5 Data and methods

The applied data set consists of monthly time series data from the five U.S. based commodity markets for corn, soybeans, wheat, WTI and copper. The data set covers the time period from March 1990 to December 2012. As for copper, storage data were only available for the period of October 2001 to December 2012. This commodity will therefore be tested on a shorter time period.

The price data is taken from the publicly accessible data base www.wikiposit.com[8]. The original data sources are reported to be the Chicago Board of Trade (CBOT) for corn, soybeans and wheat, New York Mercantile Exchange (NYMEX) for WTI, and the Commodity Exchange (COMEX), a division of the New York Mercantile Exchange, for copper. The inventory levels are taken from the United States Department of Agriculture's (USDA) quarterly report on grain stocks and the weakly numbers reported by the U.S Energy Information Administration's (EIA). The COMEX copper inventory data was obtained through a reliable internal source at the Norwegian University of Life Sciences. The interest rate is represented by three months U.S. Treasury bill rates, also collected from the wikiposit data base.

A well known problem when analyzing commodity markets is the lack of frequently and consistently measures of the spot price. Since the spot price is an important variable when measuring the convenience yield, this problem is usually solved by employing the front futures contract as a proxy for the spot price (Fama & French 1987; Lin & Duan 2006). This approach will also be used in this study. Using futures prices as a proxy for the spot price is advantageous since these prices are settled on a daily basis, and are based on the same standardized commodity grad. This provides both frequent and consistent observations. Table 1 summarizes the specifications of the included contracts.

Table 1: Contract specifications of the five included commodities

Commodity	Grade	Delivery months	Exchange	Measurement
Corn	#2 Yellow	Mar, May, Jul, Sep, Dec	CBOT	¢/bushel
Soybeans	#2 Yellow	Jan, Mar, May, Jul, Aug, Sep, Nov	CBOT	¢/bushel
Wheat	#2 Soft Red Winter	Mar, May, Jul, Sep, Dec	CBOT	¢/bushel
Crude oil	WTI Light Sweet Crude Oil	Every month	NYMEX	$/barrel
Copper	High Graded Copper	Mar, May, Jul, Sep, Dec	COMEX	¢/pound

[8] During this writing, the data found at the domain www.wikiposit.com has been transferred to the domain www.quandl.com. The data still remains the same.

5.1 *Calculating the Convenience Yield*

Referring to the literature review, the convenience yield is not an observable statistic. Still, by assuming stable storage costs, the net cost of storage has proven to serve well as a proxy for the convenience yield. Thus, by following the continuous pricing model from equation 5, a system for calculating this variable can be derived. By taking the natural logarithms on both sides of equation 5 and rearrange, the following relationship occurs,

$$F_{t,T_2}^{D} = F_{t,T_1}^{N} e^{(i+c-y)\tau}$$

$$lnF_{t,T_2}^{D} = l\,n\,F_{t,T_1}^{N} + (i_t + c_t - y_t)\tau$$

$$\frac{lnF_{t,T_2}^{D} - lnF_{t,T_1}^{N}}{\tau} - i_t = (c-y)_t = NCS_{N-D} \quad (6).$$

In equation 6, lnF_{t,T_2}^{D} is the natural logarithm of a distant futures contract's price at time t with maturity at time T_2, and lnF_{t,T_1}^{N} is the natural logarithm of the front futures contract at time t, with maturity at time T_1, indicating $T_2 > T_1$. The time factor is represented by the term $\tau = (T_2 - T_1)$, while i, c and y refers to the interest rate, storage cost and the convenience yield, respectively. The same calculation is also used by Mazaheri (1999), Kremser and Rammerstorfer (2010) and Symeonidis (2012) among others. NCS_{N-D} is the acronym for the net cost of storage between the near and distant futures contract. Throughout the rest of the paper NCS_{1-n} will denote the net cost of storage as calculated from equation 6, between the 1th and an nth distant futures contract.

More specific, F_{t,T_1}^{N} is here set equal to the daily price of the front contract, while F_{t,T_2}^{D} is the daily price of a distant futures contract. These contracts are rolled over every maturity month, creating a continuous time series of prices. The rollover of the contracts happens eight days before the delivery date, which is normally set to the working day closest to the 15th day of the delivery month. On rollover day, the 2th contract becomes the 1th, the 3rd contract becomes the 2nd etc[9].

[9] www.cme.com offers a more detailed explanation of contract rollovers.

The new price that occurs on rollover day is usually close to the price of the old contract, due to the converging nature of the two contract prices (Hull 2012). Still, this convergence sometimes fails, causing large fluctuations in the commodity price at the rollover day. An empirical example is given later on in this chapter.

The formula in equation 6 is used to calculate the daily values of the convenience yield. The interest rate, represented by the yearly rate of a three month Treasury bill, is thereby also calculated into daily values[10]. Due to the continuous form of the underlying equation, the NCS must be interpreted as a percentage proportion of the nearby futures price.

To smooth out the noise associated with the rollover of the contracts, the daily values of the NCS are averaged across each month of the year, similar to the method used by Lin and Duan (2006). The daily average values are calculated into monthly values by multiplying them with 30. The variables obtained through this method are used as a proxy for the convenience yield.

The number of different NCS rates calculated in this thesis is decided by the number of contracts that matures within a year for each commodity. E.g. during a twelve month period, the wheat contract at COBT has five deliveries. This creates four unique variables of the NCS based upon the spread between the 1th and the 2nd, the 1th and the 3rd, the 1th and the 4th, and the 1th and the 5th contract. Or by using a simpler notation, $NCS_{1\text{-}2}$, $NCS_{1\text{-}3}$, $NCS_{1\text{-}4}$ and $NCS_{1\text{-}5}$.

As for the rest of the commodities, four different NCS variables will be calculated for corn and copper and six variables for soybeans. The WTI contract has originally 12 deliveries within a year, but only the $NCS_{1\text{-}2}$, $NCS_{1\text{-}3}$, $NCS_{1\text{-}6}$, $NCS_{1\text{-}9}$ and $NCS_{1\text{-}12}$ will be included in this study. Through this method it becomes possible to analyze the yearly term structure of the NCS making it possible to see how the yearly business cycle of the different commodities affects the convenience yield. A more detailed description of the time relation between the different NCS spreads is included in the appendix.

Figure 2 present two graphs displaying the $NCS_{1\text{-}2}$ for the five commodities.

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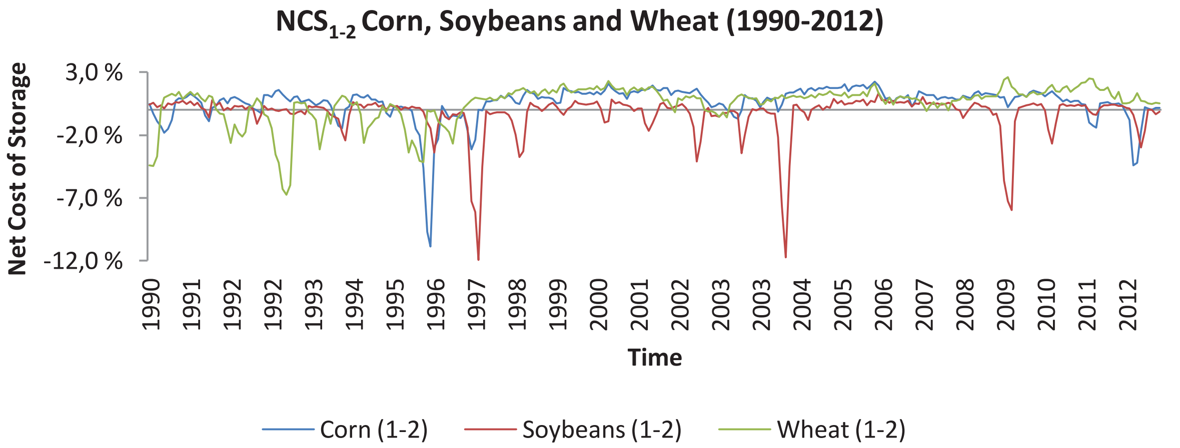
[10] The yearly three month U.S. Treasury bill is calculated into daily values by $TB_{Daily} = (1 + TB_{Yearly})^{\frac{1}{365}}) - 1$, where TB_{Daily} is the daily percentage value of the three month U.S Treasury bill and TB_{Yearly} is the yearly percentage value of the three month U.S. Treasury bill.



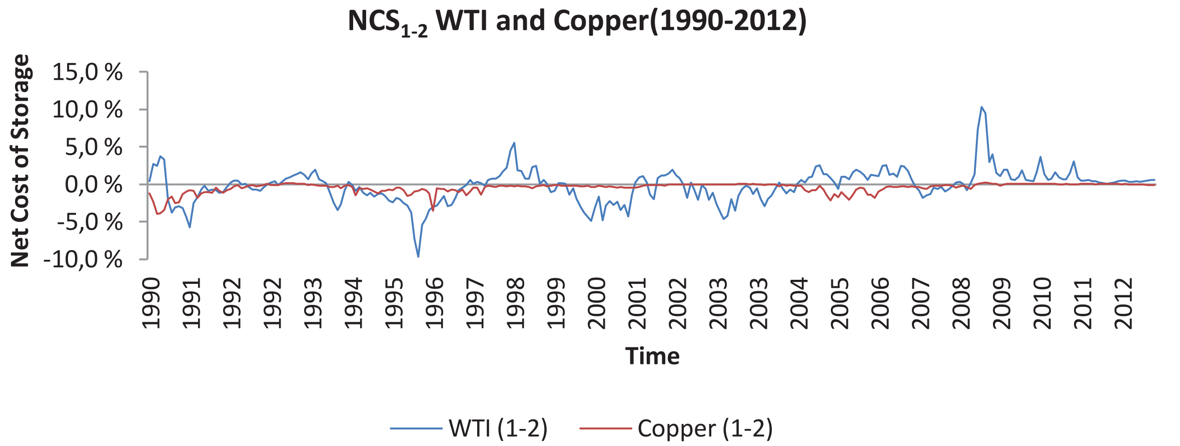


Figure 2: Net Cost of Storage between the first and second futures contract (1990-2012). Upper chart: Corn, Soybeans and Wheat. Lower chart: WTI and Copper.

From the upper graph it is possible to see that the cash and carry arbitrage argument seems to be fulfilled for the three agricultural commodities. This can be argued by looking at the positive values of the NCS, that tends to be constrained by an upper bond of approximately 2,0% of the spot price. This indicates that the futures price of the second contract never exceeded the price of the front contract by more than this amount. According to the cash and carry arbitrage argument, 2,0% can thereby be interpreted as the approximately maximum monthly storage cost. The negative values, representing periods where the convenience yield is large, are on the other hand not affected by such a constraint.

The lower graph indicates that copper follows the same pattern, except that the positive values appear to be much lower. An explanation to this could be that storing of copper demands relatively uncomplicated storing facilities, which indicates a lower cost of storing. Still, considering that the copper price per pound is rather low in nominal terms, the proportionate storage cost should be expected to be higher. This could indicate that the futures price for copper experiences a significant convenience yield.

On the other hand, the cash and carry pattern does not apply very well considering WTI. Throughout the time period from 1990 to 2012 there are three periods (1990-1991, 1998-1999 and 2009-2010) where the NCS tends to hold extraordinarily high values. The same pattern is found by Knetsh (2007), estimating the convenience yield on brent crude oil.

The spikes of the NCS seem to be positively correlated with periods of increasing oil prices. The extra growth in the 2nd futures price could therefore have been caused by a risk premium, paid by long hedgers who wished to secure them self against additional increases in the WTI price during these time periods.

5.2 The effect of contract rollovers and harvest cycles

As described earlier on in this chapter, large convenience yields can often be a result of contract rollovers at times when the price convergence between two contracts fails. This phenomenon was especially present in the market for CBOT corn in 1996. Thus, corn prices from this particular year are used to demonstrate how rolling of contracts and failed price convergence affects the NCS.

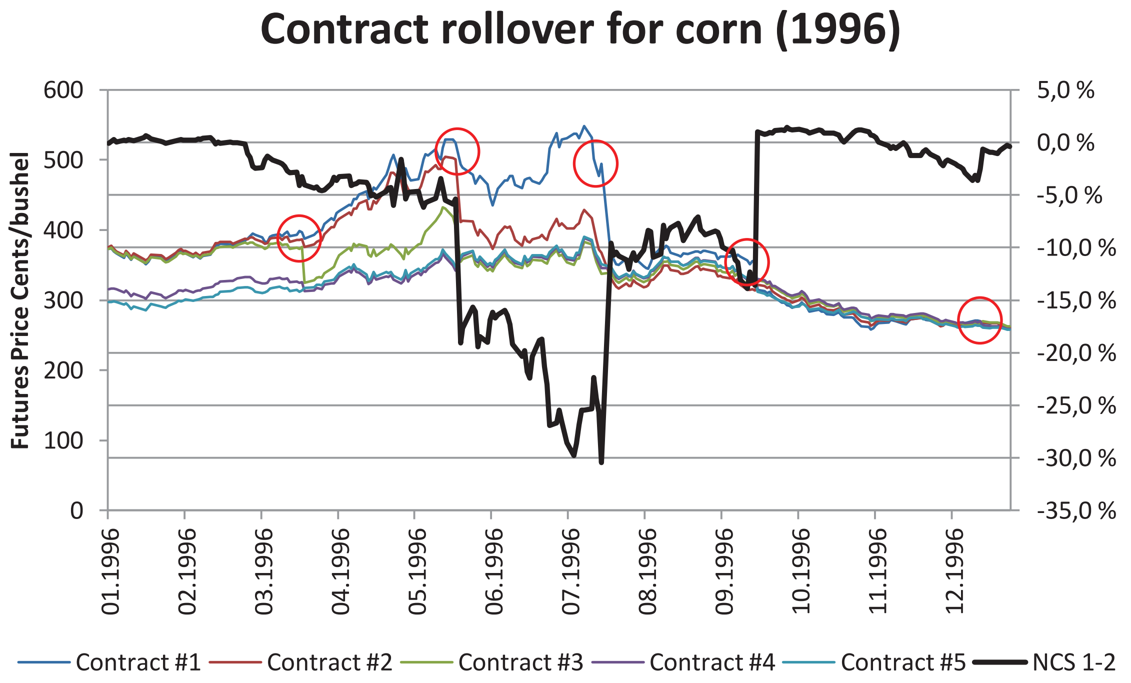
Table 2 states the next delivery month for the five first futures contracts of corn after each rollover.

Table 2: Contract rollover cycles for Corn.

Delivery Month	Contract #1	Contract #2	Contract #3	Contract #4	Contract #5
March	Mar. -->May	May --> Jul.	Jul. --> Sep.	Sep. --> Dec.	Dec. -->Mar.
May	May --> Jul.	Jul. --> Sep.	Sep. --> Dec.	Dec. -->Mar.	Mar. -->May
July	Jul. --> Sep.	Sep. --> Dec.	Dec. -->Mar.	Mar. -->May	May --> Jul.
September	Sep. --> Dec.	Dec. -->Mar.	Mar. -->May	May --> Jul.	Jul. --> Sep.
December	Dec. --> Mar.	Mar. -->May	May --> Jul.	Jul. --> Sep.	Sep. --> Dec.

The low inventory levels of corn in December 1995 led to the lowest July inventory level recorded in this data set the following year. The low inventory stock resulted in an increase of the intrinsic value of holding physical corn, making the price convergence between the three nearest contracts much weaker.

Figure 3 depicts the price of the five first futures contracts, the daily $NCS_{1\text{-}2}$, and the trading volume for the 1st contract for CBOT corn in 1996. The NCS values used in the figure is the total daily NCS and are not divided by any time factor. Rollover days are market with red circles. By combining the information in table 4 and the graphs above, it is possible to sew how the rollover of the contracts affected the prices and the NCS for this specific year.



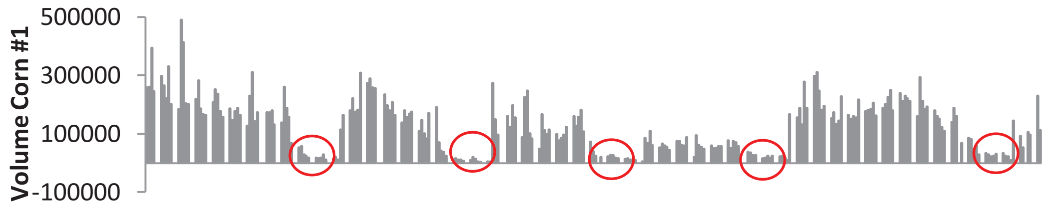


Figure 3: Upper chart: Daily prices from the five first corn futures contracts and the daily NCS between the 1st and the 2nd futures contract in 1996. Lower chart: Trading volume of the front corn contract throughout 1996

First thing to notice is that the 4th and the 5th contract follow each other closely throughout the whole period and are not affected significantly be the contract rollovers. This is due to the fact that these two contracts represent a different storage scenario relative to the three first contracts, since both are set for delivery on the other side of the harvest period after being rolled over in March.

In March, representing the first maturity month of the year, a lack of convergence between the 3rd and the 4th contract makes the price of the 3rd contract to drop by approximately 50 cents when it is rolled over into a September contract. This equals a price drop of nearly 13,5% in one day.

A similar plunge occurs when the 2nd contract is rolled over into a September contract, as the rollover in May takes place. At this point the 2nd contract decreased with almost 100 cents, indicating a one-day price drop of 17,5%. The front contract, that now had become the July contract, did not decrease nearly as much. At this point, the failing convergence between the 2nd and the 3rd contract led to an immediate drop in the NCS. The large fall indicates an increase in the convenience yield, and gives good visual evidence on how the intrinsic value of having corn delivered in July is much higher than having it delivered in September when stocks are critically low.

This is also demonstrated when the front contract is rolled over into a September contract, making the price of the contract to decrease by more than 100 cents. The convenience yield of owning the futures front contract instead of the 2nd contract remains above the gross storage cost, but continuous to decrease up until the front contract is rolled over into a December contract. At this point the market shifts back into contango, and the return of storage becomes positive once again. Since the December contract is delivered after the harvest period, the fear of an immediate stock out disappears, making the convenience yield of nearby delivery smaller.

From the lower chart, presenting the trading volume of the front contract, it is possible to see that the contract with delivery in July was actively traded in the period from May to July, despite a large backwardation. The willingness to pay premiums of more than 30% of the expected future price indicates a significant excess value of holding physical commodities during times with low inventory levels. The particular case of 1996 corn prices offers a nice visual impression on how the convenience yield is affected by the fear of stock outs and failed price convergence between the contracts.

The case of backwardation in corn prices in 1996 is indeed an extreme case of how rollovers of contracts can influence the NCS. Still, similar patterns are found among all the three agricultural commodities. Examples can be found in wheat prices during 1990, 1993, 1996, and in soybean prices during 1997, 2004, 2009. These cases will on the other hand not be debated in this thesis.

The case of corn prices from 1996 signifies that the September contract seems to be a critical contract regarding how the market comprehends the storage situation. Since the September contract usually is delivered right before the next harvest, it seems that reliable information about the next harvest is also an important factor affecting the convenience yield.

The volume chart in figure 3, points out how the liquidity of the contract falls right before rollover days and picks up after the contract is rolled over. Since this is a cyclical and rather deterministic process for most commodity futures, it is natural to believe that rational speculators switch their position before the rollover takes place. Assuming this, the contracts held right before rollover is mainly owned by commercial hedgers who indicate to go through with the delivery of the contract, signifying that the markup in the price do reflect some of the assumed properties of the convenience yield.

5.3 Inventory data

The inventory levels applied for corn, soybeans and wheat is the total aggregated U.S. stocks reported by the USDA. This total stock is made up by the entire inventory held by producers, mills, elevators, warehouses, terminals and processors across the U.S. measured in metric tons. The inventory levels of crude oil are the weekly ending stocks measured in number of barrels, reported by the EIA. Copper inventory is the monthly COMEX storage level reported in short tons.

Regarding wheat, it should be mentioned that the USDA reports the total aggregated stock of all wheat types held in the country. This aggregation of data could possibly weaken the analysis due to the fact that different strains of wheat holds different harvesting cycles and are traded with different futures contracts on separate exchanges[11].

[11] Hard red spring wheat is primarily traded at the Minneapolis Grain Exchange, hard red winter wheat is primarily traded at the Kansas City Board of Trade, and soft red winter wheat is primarily traded at the Chicago Board of Trade.

Nevertheless, the soft red winter wheat contract traded at the CBOT is the biggest contract measured in trading volume, and is usually the one referred to as the reference price for wheat in the U.S. It should thereby, due to its liquidity and position, be the best fitted contract for analyzing the inventory's effect on the NCS. Still, the careful reader should be aware that the inventory data used in this analysis also contains other wheat types than CBOT's soft red winter wheat.

Referring to the literature review, many commodities are commonly expected to experience seasonality in their stock levels. This expectation applies especially to agricultural commodities, due to their deterministic harvesting cycles. The seasonal cycles found in the inventory data are presented graphically in figure 4-8.

The points in the graphs represent the inventory level measured quarterly, starting on March 1 each year. The red line is the four quarter moving average.

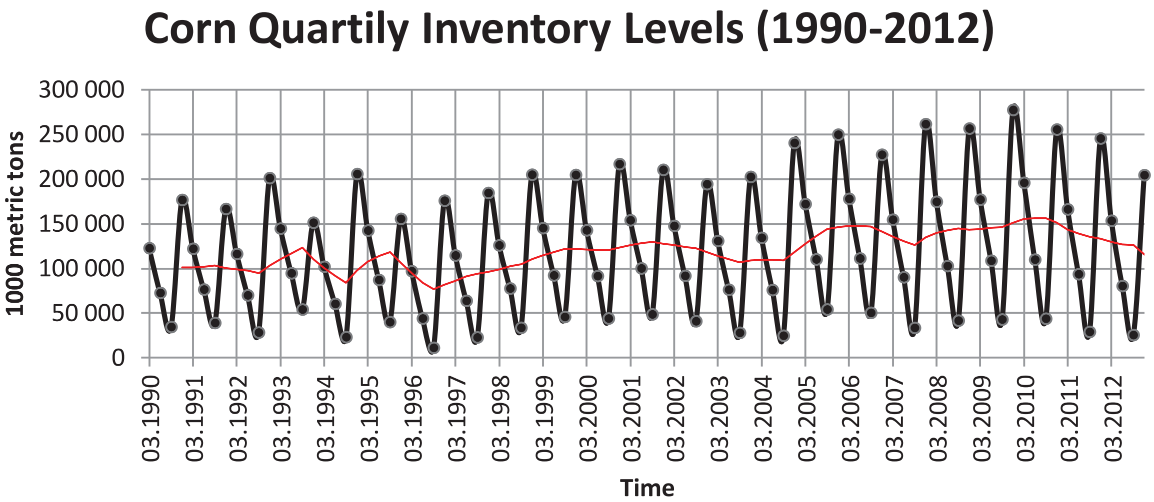


Figure 4: Quarterly inventory level for Corn (1990-2012) measured in 1000 metric tons (Source: USDA)

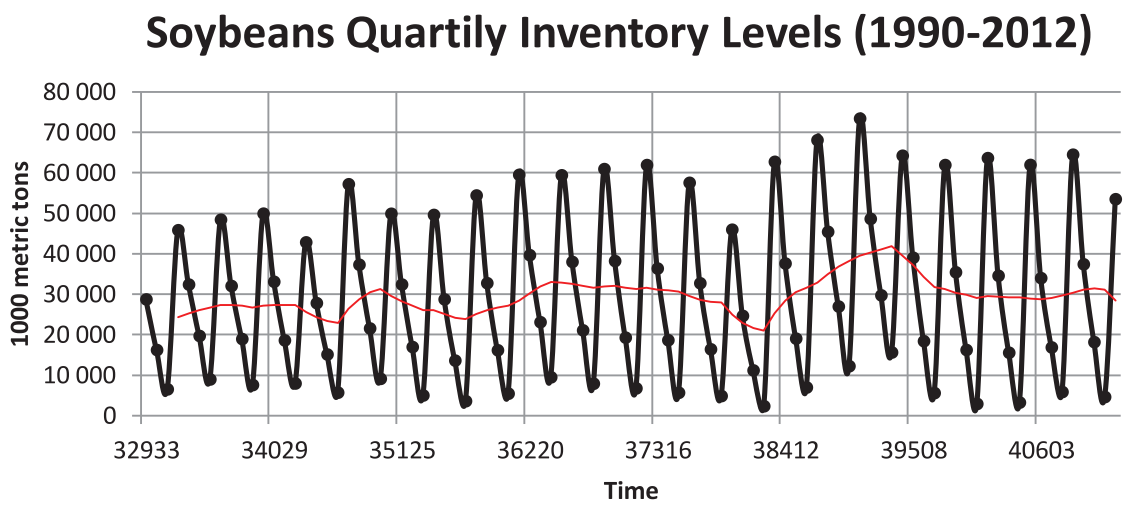


Figure 5: Quarterly inventory level for Soybeans (1990-2012) measured in 1000 metric tons (Source: USDA)

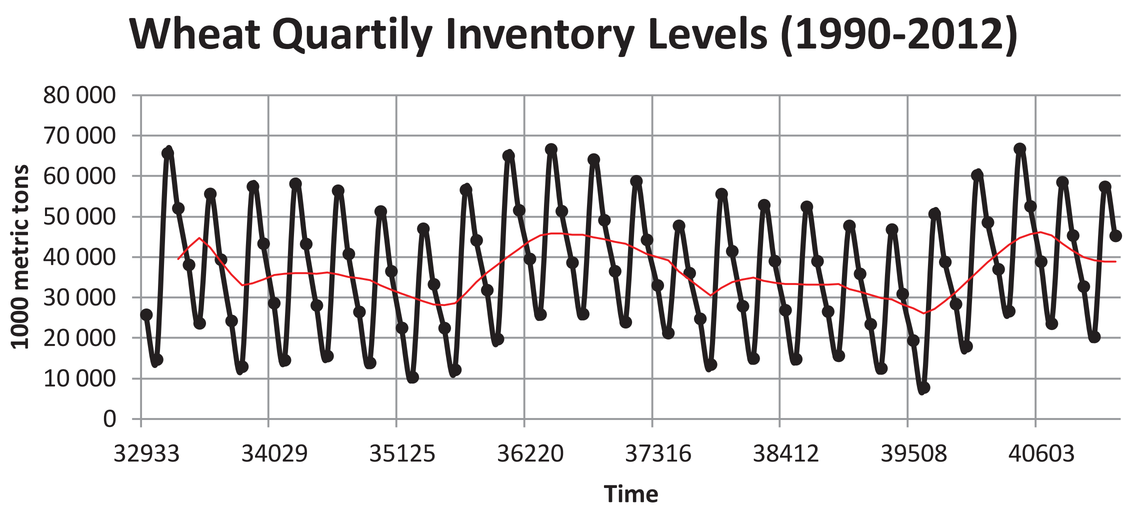


Figure 6: Quarterly inventory level for Wheat (1990-2012) measured in 1000 metric tons (Source: USDA)

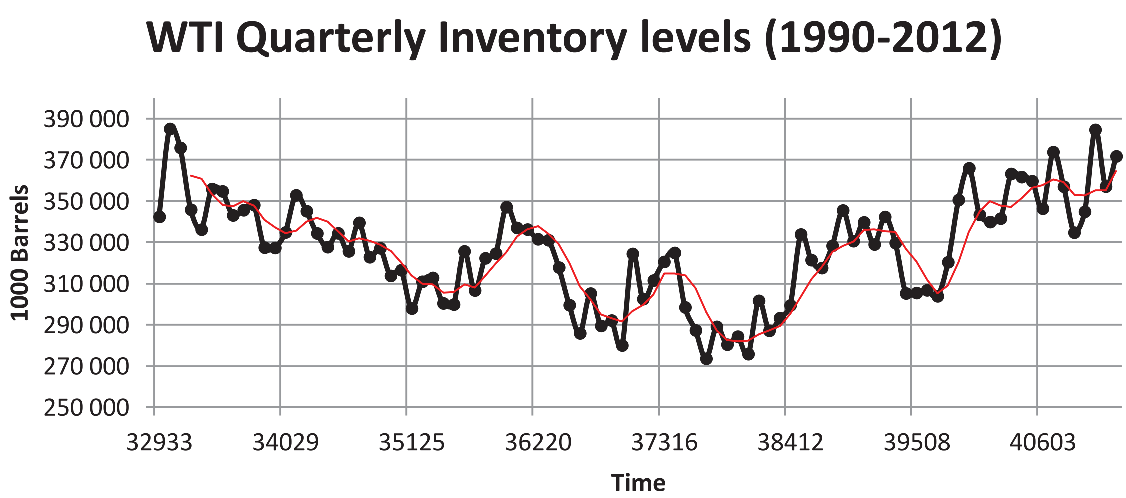


Figure 7: Quarterly inventory level for WTI (1990-2012) measured in 1000 of barrels (Source: USEIA)

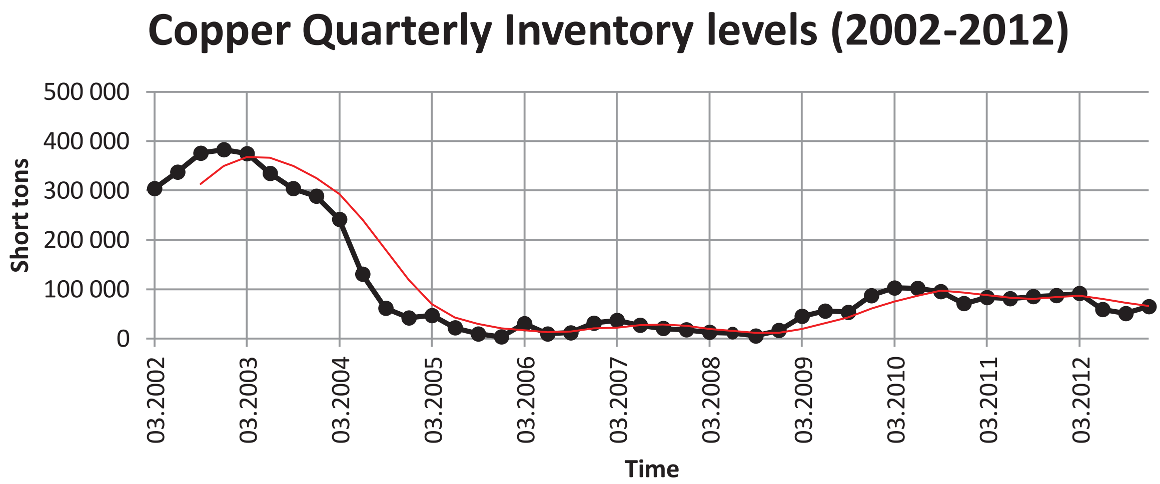


Figure 8: Quarterly inventory level for Copper (2002-2012) measured in metric tons (Source: COMEX/Internal)

As expected, the pattern found among the agricultural commodities is deterministic, repeating itself year after year. This was not the case for WTI and copper, since the extraction of these commodities are not influenced by any particular seasonality.

In figure 4 and 5 it is possible to see that corn and soybeans share the same seasonal patterns. This is also to be expected, since both commodities share the same harvesting cycle, as harvest normally lasts from September throughout November. This leads to a repeating supply cycle, where the supply decreases in the first three quarters of the year, then increases in the last quarter when newly harvested crops are added to the inventory.

The inventory of wheat offers a similar pattern, but since the harvest of this commodity starts earlier as winter crops are being harvested between May and July, the inventory levels starts to increase already in the third quarter of the year. The harvest period of wheat normally ends in the middle of September when the crops planted in the spring are harvested. Thus, wheat inventory usually declines in the two first and the last quarters of the year, and increases in the third.

According to the theory of storage, these seasonal patterns indicate that the convenience yield is at its highest during the months previous to July concerning wheat, and in the months previous to September concerning corn and soybeans. This is because the inventory levels can be expected to be at their lowest during these months.

Regarding WTI, the inventory levels do not experience the same deterministic seasonal pattern, as found within the grain-based commodities. This is also to be expected since crude oil does not have any particular seasonal constrains for when it can be extracted. The lack of any clear seasonal pattern makes it hard to give good predictions on how inventories will affect the timing of the convenience yield throughout the year.

The inventory data for copper traded at COMEX was only available for the time period October 2001 to December 2012. The graph in figure 8 points out that copper inventory, similar to WTI, does not hold any seasonal trend. This was also to be expected since copper also can be extracted all year round. From the graph in figure 8, it is possible to see how the copper inventory started to decrease drastically in the early years of the last decade. This can mainly be linked to the increasing demand of construction and industrial commodities in China and some of the other BRIC[12] countries during this time period.

To obtain monthly values of the inventory levels, a linear interpolation method is used. The quarterly storage levels were interpolated into daily values, and then averaged across each calendar month of the year. The copper inventory was already reported on a monthly basis and has thereby not been treated with the interpolation method.

The assumption that inventory levels should increase or decrease linearly between months can indeed seem a bit strong. Nevertheless, since commodities commonly are known to hold a fairly stable supply and demand on short terms, this approximation should not affect the analysis with much significance, since the frequency of the original data ensures that the seasonal patterns are captured by the interpolated data as well.

[12] Brazil, Russia, India and China

Table 3: Descriptive statistics for monthly inventory levels of corn, soybeans, wheat, WTI and Copper* (1990-2012)

Commodity	Corn	Soybeans	Wheat	WTI	Copper
Average	118 895	29 322	36 461	325	110 793
Median	114 446	28 289	35 745	328	61 619
Standard deviation	54 515	15 278	12 552	26	119 069
Coefficient of variation[13]	0,46	0,52	0,34	0,08	1,07
Max	263 351	69 283	64 405	388	399 341
Min	16 527	3 876	9 714	266	3681

Corn, soybeans and wheat are measured in 1 000 metric tons, WTI in 1 000 000 barrels and copper in short tons

***Copper inventory was only available from October 2001 to December 2012.**

Table 3 presents some descriptive statistics for the inventory levels. By comparing the numbers for the three agricultural commodities, it is possible to see that corn is by far the mostly produced, followed by wheat, then soybeans. By focusing on the variation coefficient of the commodities, it is possible to see how wheat obtains a lower coefficient than corn and soybeans. This can probably be related to a longer harvesting period for wheat.

WTI obtains the lowest coefficient of variation, as this commodity is continuously extracted, making the fluctuations in the supply much smaller, compared with the agricultural commodities.

The variation in copper inventory is clearly affected by the large decrease in inventory, between 2003 and 2005. Still, the variation coefficient for copper inventory remains high (0,64) also after 2005. This indicates that this commodity is postponed to a rather unstable supply.

5.4 Econometric model

Working (1948) suggested a strong relationship between the basis of commodity prices and the inventory level. Referring to this, the NCS can be expected to be a function of the inventory level. Workings main empirical finding said that the value of the basis tends to be positively correlated with inventory levels, indicating that low inventories often are followed by low or even negative values in the NCS. By combining this theory with the maximum constrain of the cash and carry arbitrage argument, the function $NCS = f(I)$, where $f(I)$ represents the inventory level, is given the following properties, $\frac{\partial NCS}{\partial I} > 0$ and $\frac{\partial^2 NCS}{\partial^2 I} < 0$. This

[13] Coefficient of variation = Standard deviation/average value

results in an upward sloping concave function. The maximum constrain on the positive values of the NCS, signifies that when $I \to \infty$ then $\frac{\partial NCS}{\partial I} \to 0$, ensuring that the cash and carry arbitrage argument is maintained. The empirical curve of $NCS = f(I)$ should thereby be a concave function similar to the one presented in figure 9.

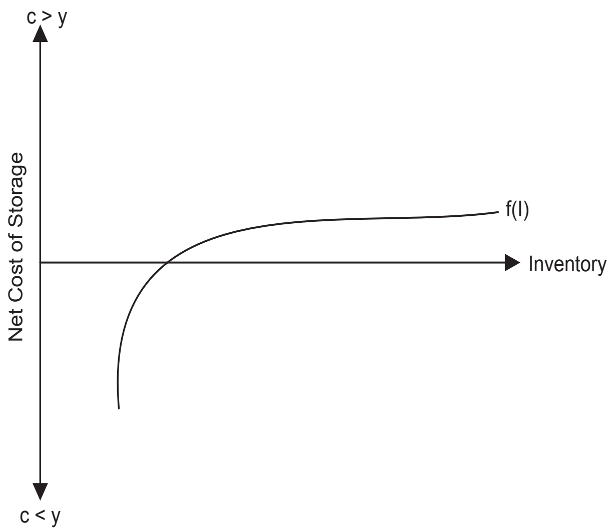


Figure 9: NCS as a function of the inventory level

As proposed by Samuelson (1965) and verified by Fama and French (1987) and Duan and Lin (2010, 2006), distant futures prices are less volatile compared with spot prices during periods with low inventory levels. Thus, there should be a relationship between the relative price volatility and the NCS as well. By taking spot price volatility as a fraction of the futures price volatility, this variable is assumed to be positively correlated with the convenience yield, making it negatively correlated with the NCS. The function $NCS = f(V)$, where V is the relative price volatility between the spot price and the futures price, is given the following properties $\frac{\partial NCS}{\partial V} < 0$ and $\frac{\partial^2 NCS}{\partial^2 V} > 0$, resulting in a downward sloping concave function.

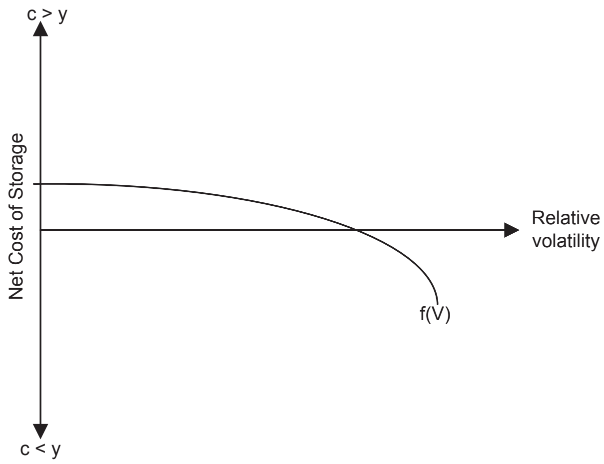


Figure 10: NCS as a function of spot price volatility relative to futures price volatility

A third argument linked to the NCS through the theory of storage, is the interest rate. Since commodities in physical form do not yield any derived payoff of monetary value, the interest rate represents a capital cost of holding physical commodities. The capital cost of holding a physical commodity instead of a futures contract, can be calculated as

$$CC_{t,T} = S_t * i_t * (T - t), \tag{7}$$

where $CC_{t,T}$ is the capital cost that arises in the time period from t to T, S_t is the spot price of the commodity at time t, and i_t is the interest rate (Joseph et al., 2011). In this thesis, the capital cost will be calculated be multiplying the price of the front futures contract with the daily rate of a three month U.S. Treasury bond. These numbers are then multiplied by the amount of days between delivery of the front contract and a respective distant futures contract. An increase in the capital cost should theoretically increase the total cost of carry and is thereby assumed to be positively correlated with the NCS. The function $NCS = f(CC)$ is given the following properties, $\frac{\partial NCS}{\partial CC} > 0$ and $\frac{\partial^2 NCS}{\partial^2 CC} = 0$ resulting in an upward sloping linear line. Since the capital cost adds to the total cost of storage, this variable is not constrained by any upper value of the NCS.

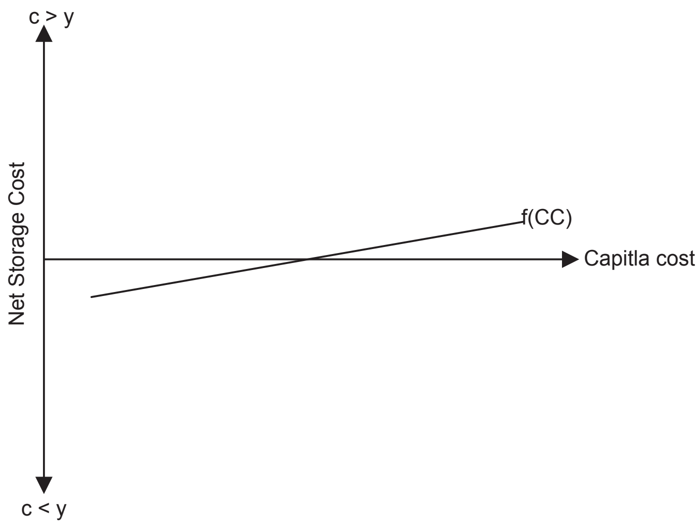


Figure 11: NCS as a function of capital cost

These three variables give the function $NCS = f(I, V, CC)$. Based on the different properties imposed on the variables the following functional form is proposed,

$$NCS_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\ 2} + \beta_3 \Delta CC_{1,n,t} + \varepsilon_{1,n,t} \qquad (8).$$

In equation 8, α and $\beta_{1,2,3}$ represent the linear parameters of the model and $\varepsilon_{1,n,t}$ is the i.i.d. residual term. The variable I_t^{-1} represents the inverse inventory level at time t, V^2 is the squared relative price volatility between the spot price and a distant futures price, and $\Delta CC_{1,n,t}$ is the relative change in the capital cost. The dependent variable $NSC_{1,n,t}$ is the monthly proportionate net cost of storage, calculated as the interest adjusted relative basis between the 1^{th} and the n^{th} futures contract, as explained in equation 6. The model holds no lagged variables due to the assumption of efficient information flow, which ensures that all historical information relevant to the NCS already should be incorporated into the underlying prices.

The inventory's effect on the NCS is given by the reciprocal term $\beta_1 \frac{1}{I}$, where I represents the inventory level measured in 1000 metric tons for corn, soybean and wheat, 1 000 000 barrels for WTI and short tons for copper[14]. The reciprocal form holds nice asymptotic features as $\beta_1 \frac{1}{I} \to 0$ when $I \to \infty$, ensuring that the maximum condition imposed by the cash and carry arbitrage argument is maintained. This functional form is also used by Brennan (1958).

[14] 1000 metric tons = 1102 short tons.

The marginal effect of the reciprocal term is $\frac{\partial NCS}{\partial I} = -\beta_1(\frac{NCS}{I^2})$, indicating that the expected sign of β_1 in this case should be negative, making the marginal effect positive.

The second term of the model is the relative price volatility. In this term $V = (\frac{\sigma_{1,t}}{\sigma_{n,t}})$, where $\sigma_{1,t}$ denotes the volatility of the spot price, calculated as a twenty days rolling standard deviation of the front contract price, and $\sigma_{n,t}$ is the corresponding twenty days rolling standard deviation of the n^{th} futures contract price. These standard deviations are then averaged across each calendar month throughout the data set, and then calculated into a relative volatility variable by dividing the spot price volatility on the corresponding futures price volatility.

In the applied data set, twenty days of price data is approximately equal to one calendar month due to holidays and other non-working days. Thus, the average standard deviation in e.g. April is based on price fluctuations in March, April and May. This should smooth out some of the effect caused by potentially extreme daily values.

When testing the model, the $NCS_{1\text{-}2}$ will be regressed against the relative volatility based on the 1st and 2nd contract and so on. The term enters the model squared, giving more weight to the values that occurs when the spot price volatility tops the futures price volatility, indicating a concave relationship. β_2 is expected to have a negative sign, referring to Samuelson's hypothesis that more insecurity in spot prices should increase the convenience yield, thus lowering the NCS. The marginal effect of the variable is $\frac{\partial NCS}{\partial V} = 2 * \beta_2 * V$.

The term representing the capital cost enters the model as the relative change in the variable, calculated as $\Delta CC = \frac{CC_t - CC_{t-1}}{CC_{t-1}}$. Each variable of the NCS will be tested against its corresponding capital cost. The $NCS_{1\text{-}3}$ contract will then be regressed against the capital cost for the time period between these two contracts. Since the capital cost adds to the total cost of storage β_3 is expected to be positive.

Similar explanatory variables as those presented in equation 8 have been tested by Lin and Duan (2010), Mazaheri (1999) and Carbonez et.al. (2010).

The theory of storage argues that low inventory levels have great influence on the intrinsic value of the commodity. Low inventories create fear of stock-outs and are assumed to make inventory holders more reluctant to sell their stocks. This give rise to a question regarding what levels of inventory can be seen as critically low? The model presented in equation 8, does not capture the effect of what the market actually considers as low inventories.

To adjust for this effect, an additional term in form of a binominal variable is included. This variable will be based on whether the inventory in a specific month is below or above its five year rolling average, in the same respective month. The dummy variable is set to be equal to 1 in the case where inventory is below its five year average and 0 otherwise.

Controlling for the possible effect of a risk premium depending on the hedging pressure, as suggested by Keynes, a second dummy variable is introduced to the model. This variable measures the effect of a commercial net hedging pressure that is short. The variable is set equal to 1 when the commercial net hedging pressure is short and zero otherwise[15]. The variable is thereby meant to capture the systematic effect of a risk premium generated by a short hedging pressure.

Thus the first testable model in this paper will be

$$NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t} \qquad (9),$$

where D_{Invent} and $D_{NHP,t}$ represents the binominal dummy variable for the relative inventory and the commercial net hedging pressure, respectively. Both these variables are expected to have a negative parameter.

As discussed by Lautier (2005), commodity prices can be expected to experience seasonality. Seasonality in the prices also affects the basis between the futures contracts, as proven by Fama and French (1987) among others. This count especially for agricultural commodities since two different contracts, one with delivery before the next harvest and the other with

[15] Data on commercial contract positions are taken from the Commitments of Traders Report, published by the U.S. Commodity Futures Trading Commission (www.cftc.gov).

delivery after the next harvest, represents two different storage scenarios. Thus, they should also offer two different prices (Lautier, 2005).

Referring to this, the NCS as calculated by equation 6, can also be assumed to hold seasonal fluctuations for some of the commodities. The same assumption can be made about the relative volatility term and the inventory variable.

To see how seasonality affects the variables in equation 8, the seasonal trends must be removed. A simple way to control for deterministic seasonal fluctuations is to regress the relevant variable on a set of dummy variables meant to replicate the assumed seasonal trend (Wooldridge 2009).

$$Y_t = \gamma_t + \sum_{m=1}^{12-1} \delta_m D_m + r_t \tag{10}$$

In the equation above D_m represents a set of monthly binary dummy variables, set equal to 1 in their respective month and 0 otherwise. δ_m is the corresponding parameter. γ represents the base month, referring to the month excluded from the dummy variables set. Through this regression the monthly seasonal fluctuation gets captured by the parameters of the dummy variables, leaving the residual term r_t as the seasonally adjusted variable (Wooldridge 2009).

Thus, by saying

$$Y_t - \gamma - \sum_{m=1}^{12-1} \delta D_{m,t} = \ddot{Y}_t$$

and

$$X_t - \gamma - \sum_{m=1}^{12-1} \delta D_{m,t} = \ddot{X}_t$$

the regression model

$$\ddot{Y}_t = \alpha + \beta \ddot{X}_t + e_t,$$

will yield seasonally adjusted variables. Michael C. Lovell proved in the article *Seasonal adjustment of economic time series and multiple regression analysis* from 1963 that this regression method gives the same OLS estimates as

$$Y_t = \alpha + \beta X_t + \sum_{m=1}^{12-1} \delta D_{m,t} + e_t. \tag{11}$$

Thus, the second regression model, meant to check for the seasonal influence on the variables will be,

$$NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t} \quad (12).$$

The base months that are not included in the dummy variables, will be December for corn and soybeans, September for wheat, May for WTI and June for copper. These are the months with the highest average inventory level for each commodity throughout the applied data set. *t* is a linear variable increasing with on unit every month.

The parameters of equation 9 and equation 12, will be estimated by OSL. Newey-West standard errors are used to make the test statistics robust against autocorrelation and heteroscedasticity in the variables. In equation 12 a trend parameter increasing with one unit every year is also included to adjust for possible upward or downward trends in the variables. By carrying out comparative statistics on the estimated parameters of the models, it will also be possible to see how seasonality and trends potentially affects the variables influence on the NCS.

5.5 Tests for structural break

In addition, a test for a structural break is carried out on two sub-samples (1990-1999 and 2000-2012). The choice of the particular break point of 1990/2000 is motivated by the graph found in figure 2, as the NCS takes on a different pattern after 1999, especially regarding corn and wheat. Also the deregulation of the commodity market, following from the *Commodity Futures Modernization Act of 2000* is assumed to have altered the overall market composition, as speculation in commodity derivatives increased after this act became operative.

A Chow test is first used to uncover potential change in parameter estimates after 1999[16]. Still, the Chow test does not yield any information considering what specific variables that are postponed to a structural break. A more exact way to measure the effect of a structural break can be done by introducing an additional dummy variable into the regression, set to be equal 1 in the second sub sample (2000-2012) and 0 for the first sub sample (1990-1999). On general form this can be written,

$$Y_t = \alpha_1 + \sum_{i=1}^{n} \beta_{i,t} X_{i,t} + \sum_{i=1}^{n} \omega_{i,1} \left(D_{sub,i,t} * X_{i,t} \right) + \gamma_1 D_{sub,t} + u_t, \tag{13}$$

where $(Y_t = \alpha_1 + \sum_{i=1}^{n} \beta_{i,t} X_{i,t})$ is the base model containing *n* numbers of X variables. $D_{sub,t}$ is a dummy variable equal to 1 for observations in 2000-2012, and 0 otherwise.

By assuming $\mathrm{E}(u_t) = 0$ the following relationships occur,

$$Y_{1990-1999} = \alpha_1 + \beta_1 X_t$$

$$Y_{2000-2012} = (\alpha_1 + \gamma_1) + \sum_{i=1}^{n} (\beta_{i,t} + \omega_i) X_{i,t_t},$$

indicating that a significant γ_1 signifies a change in the intercept between the two periods, and a significant ω_i signifies a change in the variable X_i between the two periods (Gujarati and Porter 2009)

[16] Chow F-statistic = $\frac{RSS_{1990-2012} - (RSS_{1990-1999} + RSS_{2000-2012})/k}{(RSS_{1990-1999} + RSS_{2000-2012})/(n_1 + n_2 - 2k)}$ where RSS is the sum of the squared error terms from each respective model, k is the number of parameters, n_1 is the number of observations in model (1990-1999) and n_2 is the number of observations in model (2000-2012) (Gujarati and Porter 2009).

6 Empirical analyses and results

6.1 Commodity prices (1990-2012)

During the two last decades commodity prices have experienced a good deal of fluctuations caused by different incidents in the world economy. These fluctuations are presented graphically in figure 12. The included prices are the front futures contract of each commodity.

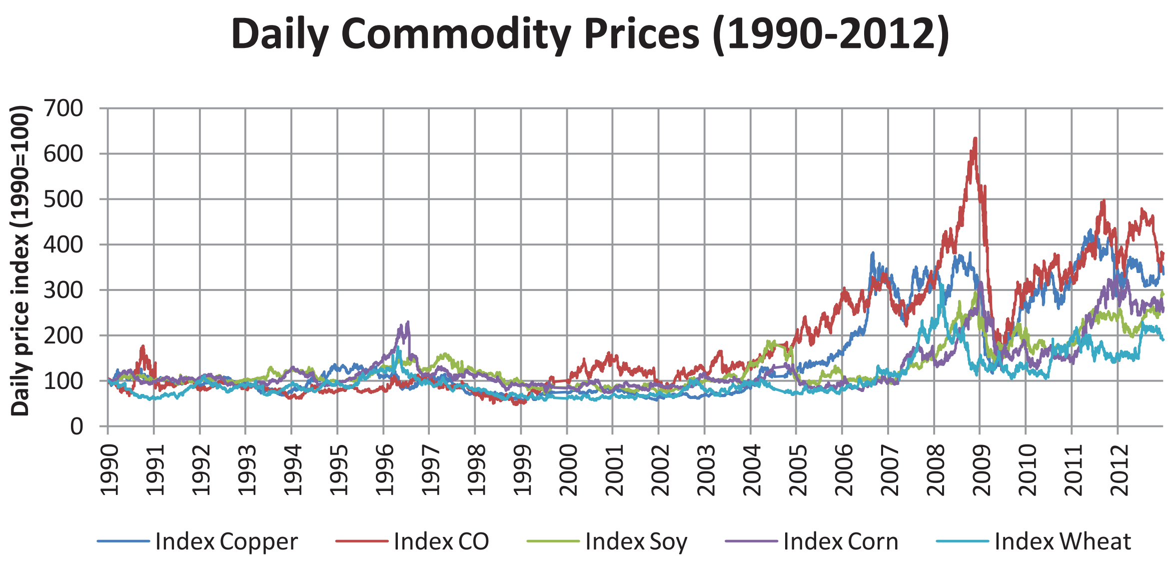


Figure 12 Daily prices for Corn, Soybeans, Wheat, WTI and Copper 1990-2012 (1990 = 100)

The sharp peak in the oil price during the last half of 1990 is often linked to Iraq's invasion of Kuwait, which naturally lead to unstable conditions in the oil production of the Arabic region. In 1996 a drought in the Midwestern states of the U.S. led to poor harvests, resulting in a lower supply of U.S. based agricultural commodities. This factor combined with an increase in demand from foreign countries for American agriculture products, subsequently led to a peak in the prices of many farm-based commodities. Figure 12 shows that corn prices, in particular experienced a great deal of increase due to this shortage of supply.

The increase in the commodity prices starting around year 2003 is often referred to as the "great commodity boom". Increasing demand from the BRIC countries resulted in a sharp boost in many commodity prices. This increase was particularly strong for commodities linked to industrial activities, like crude oil and copper, but it also affected other commodities like grains.

Moreover, an investment boom in different commodity derivatives was a decisive factor causing increasing commodity prices. This incident led to the hypothesis whether speculative investments in commodity based derivatives creates price bubbles in commodity markets (Gilbert, 2010).

As a result of the recent economical and financial crises, commodity prices followed the rest of the market down during the last quarter of 2008. In the period from 2008 to 2009, crude oil and copper prices plummeted approximately 65% and 70%, while the prices of corn, soybeans and wheat decreased by approximately 20%, 17% and 50%, respectively. In the time after the crises, commodity prices have bounced back, but the volatility in the markets still remains high.

Table 4: Descriptive Statistics for the annualized log return for Corn, Soybeans, Wheat, WTI and Copper (1990-2012)

	Corn	Soybeans	Wheat	WTI	Copper
Mean	5 %	4 %	2 %	6 %	5 %
Maximum	59 %	56 %	57 %	76 %	88 %
Minimum	-36 %	-37 %	-45 %	-77 %	-79 %
Standard deviation	24 %	23 %	27 %	37 %	35 %
Skewness	0,64	0,3	0,22	-0,29	0,06
Excess kurtosis	0,31	-0,3	-0,54	-0,06	0,87
Jarque-Bera	8,52***	10,78***	12,18***	9,28***	4,38

*****indicates that the null hypothesis "distribution is normal" is rejected at a 1% level**

Table 4 contains descriptive statistics based on the annualized returns of the futures front contract of the five commodities included in this analysis. Despite several periods with increasing commodity prices**,** the risk adjusted returns from holding commodity based futures contracts in this 22 year long period do not seem to outperform other risky asset groups.

6.2 The average Net Cost of Storage and the Convenience yield

As described in the previous chapter, the variable used as a proxy for the convenience yield is calculated as the NCS between the front contract and a distant futures contract. Table 5 presents mean values, standard deviation, and maximum and minimum values of the monthly NCS for all the included contracts and each commodity. An estimated value of the convenience yield is also included. In table 3 "NCS_{1-2}" represent the NCS based on the spread between the 1^{st} and the 2^{nd} contract, "NCS_{1-3}" represent the NCS based on the spread between the 1st and the 3rd contract, and so on. As explained through equation 6, the values of the NCS are calculated as a percentage proportion of the spot price.

Table 5: Descriptive statistics of the monthly Net Cost of Storage : Corn, Soybeans, Wheat, WTI and Copper (1990-2012)

	Mean	St.dev.	Max	Min	Convenience Yield[a]
Corn					Estimated montly storage cost: 2,1%
NCS_{1-2}	0,60 %*	0,26 %	2,24 %	-10,86 %	1,50 %
NCS_{1-3}	0,52 %*	0,22 %	1,87 %	-6,72 %	1,58 %
NCS_{1-4}	0,41 %*	0,19 %	1,73 %	-5,38 %	1,69 %
NCS_{1-5}	0,31 %*	0,18 %	1,69 %	-3,77 %	1,79 %
Soybeans					Estimated montly storage cost: 2,1%
NCS_{1-2}	-0,33 %*	0,31 %	1,35 %	-11,93 %	2,43 %
NCS_{1-3}	-0,35 %*	0,28 %	1,01 %	-9,91 %	2,45 %
NCS_{1-4}	-0,33 %*	0,21 %	0,84 %	-6,15 %	2,43 %
NCS_{1-5}	-0,31 %*	0,17 %	0,68 %	-4,70 %	2,41 %
NCS_{1-6}	-0,28 %*	0,13 %	0,52 %	-3,36 %	2,38 %
NCS_{1-7}	-0,29 %*	0,13 %	0,52 %	-2,94 %	2,39 %
Wheat					Estimated montly storage cost: 2,2%
NCS_{1-2}	0,53 %*	0,27 %	2,60 %	-6,75 %	1,67 %
NCS_{1-3}	0,13 %*	0,14 %	1,25 %	-3,49 %	2,07 %
NCS_{1-4}	0,15 %*	0,17 %	1,51 %	-3,12 %	2,05 %
NCS_{1-5}	0,13 %*	0,17 %	1,59 %	-2,90 %	2,07 %
WTI					Estimated montly storage cost: 1,0%
NCS_{1-2}	-0,21 %	0,40 %	10,32 %	-9,68 %	1,21 %
NCS_{1-3}	-0,29 %*	0,35 %	8,04 %	-8,00 %	1,29 %
NCS_{1-6}	-0,41 %*	0,27 %	4,88 %	-4,82 %	1,41 %
NCS_{1-9}	-0,45 %*	0,22 %	3,63 %	-3,88 %	1,45 %
NCS_{1-12}	-0,46 %*	0,19 %	2,98 %	-3,48 %	1,46 %
Copper					Estimated montly storage cost: 9,0%
NCS_{1-2}	-0,43 %*	0,12 %	0,26 %	-3,95 %	9,43 %
NCS_{1-3}	-0,37 %*	0,11 %	0,72 %	-3,41 %	9,37 %
NCS_{1-4}	-0,32 %*	0,12 %	2,15 %	-3,12 %	9,32 %
NCS_{1-5}	-0,07 %	0,25 %	6,71 %	-3,33 %	9,07 %

[a]the convenience yield is calculated as the estimated monthly storage cost minus the NCS. The estimation technique is presented in the subsequent paragraphs.

***indicates that the variable is significantly different from 0 at a 5% confidence level.**

Based on storage prices presented by the University of Illinois, Duan and Lin (2010) report the commercial storage cost of corn, during a seven month period starting in May, to be between 250 U.S. cents and 450 U.S cents per bushel. This approximately gives a daily storage cost of 0,166 cents per bushel. By dividing this number on the average corn price in the period of May-November from 1990-2003, a proportional monthly storage cost equal to

2,1%[17] of the spot price is calculated. The particular time space is set to avoid the large price fluctuations of the last decade. The proportionate storage cost of soybeans is according to Duan and Lin (2010) close to the number calculated for corn. The storage cost calculated in this thesis is approximately 1 percentage point lower than the proportional storage cost calculated by Duan and Lin (3,2%).

By comparing the calculated storage cost with the monthly NCS presented in table 5, it is possible to see that corn on average experienced a positive convenience yield. The increasing magnitude of the convenience yield as the time to maturity becomes longer, signifies that the term structure of the NCS for corn slopes downward.

Similarly, the average NCS for soybeans also indicates a positive convenience yield. All of the five soybean spreads have on average been in backwardation, indicating that the convenience yield has been lager than the gross cost of storage. The difference in the convenience yield values, indicate that NCS for soybeans holds a weakly upward trending term structure within a twelve month period.

The Kansas City Board of Trade reports that the maximum daily storage cost of wheat is set to 0,197 U.S cents per bushel from December throughout June and 0,296 U.S cents per bushel from July throughout November. Thus, the monthly rate charged for wheat storage is calculated to be approximately 2,2% of the spot price per bushel[18]. In this regard, the convenience yield does not top the gross storage cost, resulting in a contango market. The term structure of wheat NCS is downward sloping when moving from the second to the third contract, then flattens out for the two last remaining contracts.

Duan and Lin (2010) reports the monthly gross storage cost per barrel of crude oil to be 1% of the spot price. The negative values of the NCS, indicates that this commodity, similar to soybeans, is exposed to a positive convenience yield that exceeds the gross cost of storing on average. The term structure of the NCS is downward sloping as the values decreases as the time spread between the contracts increases.

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[17] $\left(\frac{(0{,}166)}{237{,}75}\right) * 100 * 30 = 2{,}1$, where 237,75 s the average price per bushel on CBOT Corn measured in U.S cents from 1990-2003

[18] $\left(\frac{(0{,}197+0{,}296/2)}{336{,}76}\right) * 100 * 30 = 2{,}2$, where 336,76 is the average of price per bushel on CBOT soft red winter wheat measured in U.S cents from 1990-2003. Assuming similar storage costs for KCBT and CBOT wheat.

The Chicago Mercantile Exchange Group reports the monthly storage rate per ton of copper for nine different storing facilities. The prices are from January and February in 2011 and 2012. According to these numbers, the average price for storing copper for one month is 7,32 USD/ton. This is equivalent to a monthly storage cost of 0,36 U.S. cents per pound, giving a monthly proportionate cost of 9% of the spot price. The average price of the front contract in January and February in 2011 and 2012 (4,08 U.S. cents per pound), is used to represent the spot price. The copper market has on average been in backwardation, indicating that copper also experienced a positive convenience yield. The NCS for this commodity holds an upward sloping term structure.

6.3 Empirical Working Curves (1990-2012)

The fundamental ground of the theory of storage is the proposed connection between negativity in the basis and the inventory level. Perhaps the most influential work considering this relationship belongs to Holbrook Working and his characteristic Working curve. A theoretical reproduction of the Working curve can be seen in the literature review or in Working's original article, *Theory of inverse carrying charges in futures markets* from 1948.

The Working curve offers a good visual impression on whether commodities are stored under inverted market conditions. By plotting the monthly average of the daily NCS against the corresponding inventory for each observation, a similar result occurs for all the included commodities in this study as well. The plots can be seen in figure 13-17.

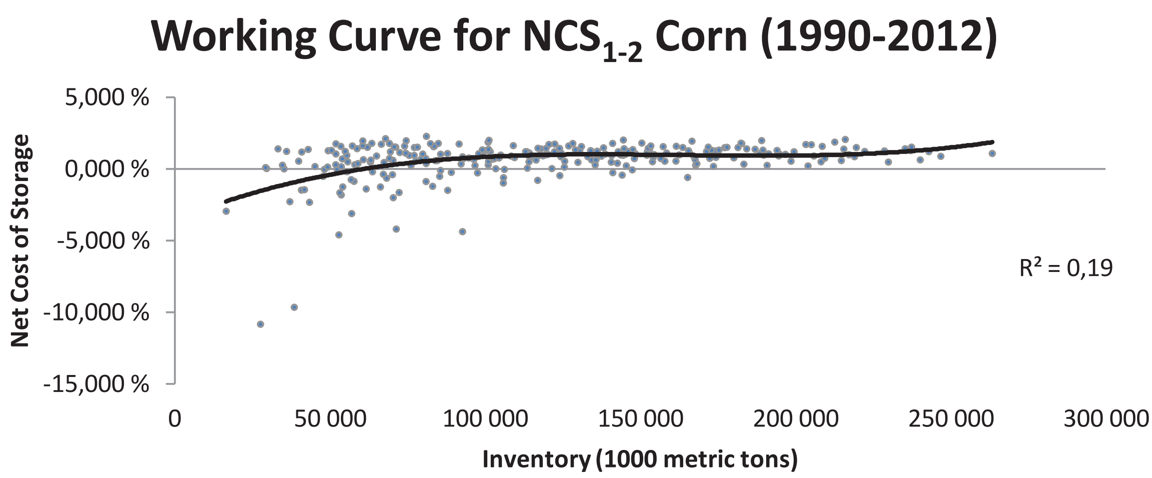

Figure 13: Empirical Working curve for Corn based on monthly NCS and storage levels from 1990-2012

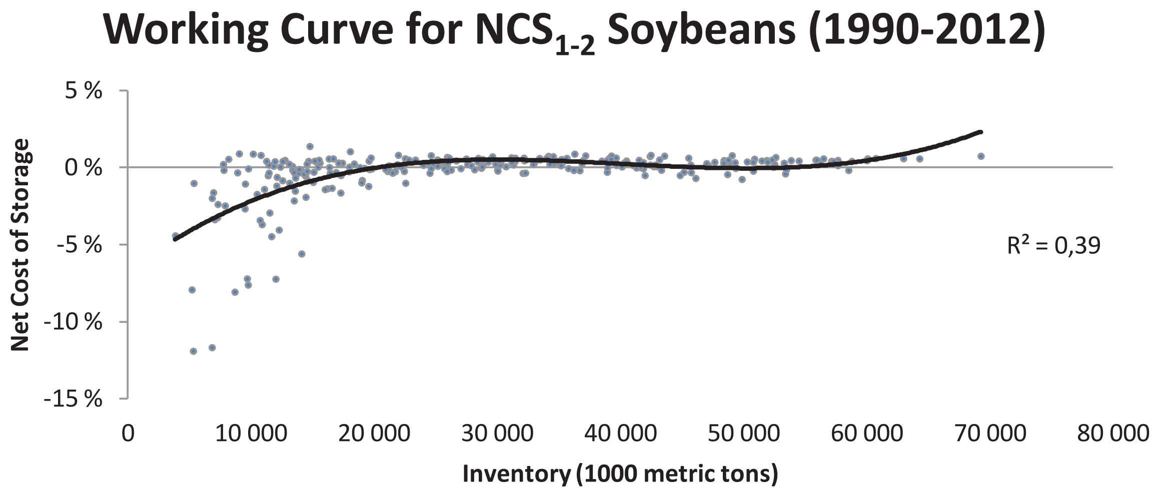

Figure 14: Empirical Working curve for Soybeans based on monthly NCS and storage levels from 1990-2012

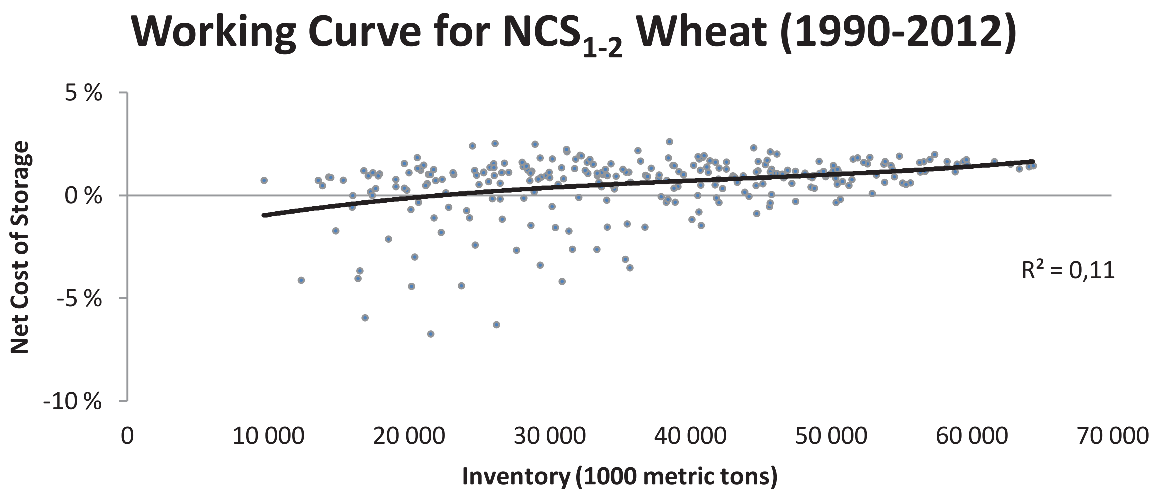

Figure 15: Empirical Working curve for Wheat based on monthly NCS and storage levels from 1990-2012

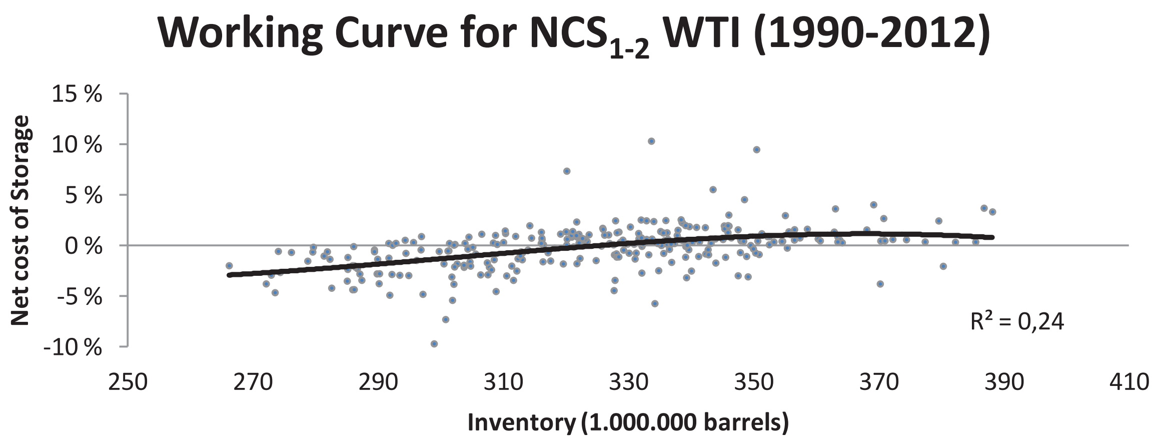

Figure 16: Empirical Working curve for WTI based on monthly NCS and storage levels from 1990-2012

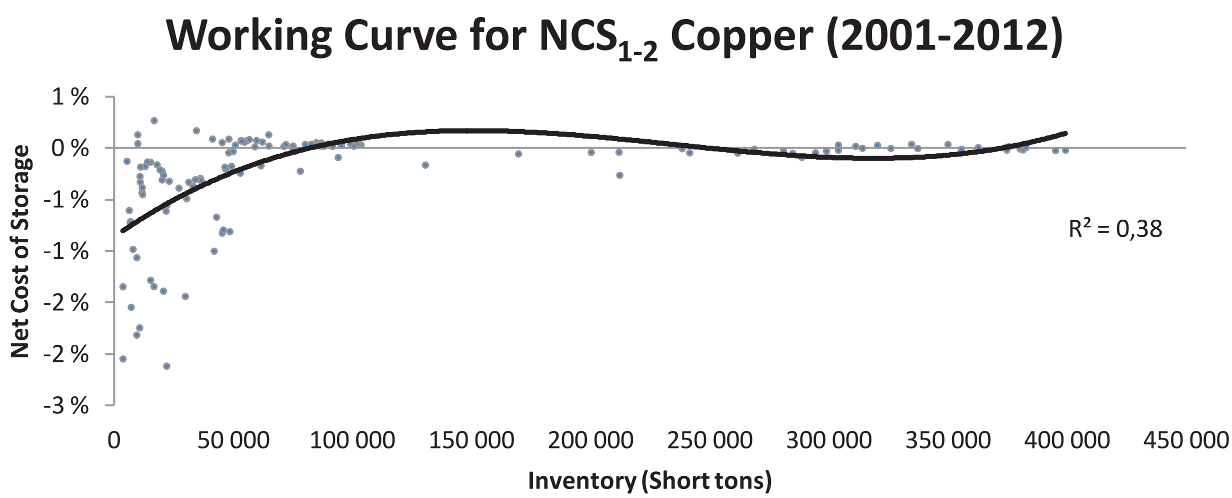

Figure 17: Empirical Working curve for Copper based on monthly NCS and storage levels from 1990-2012

The relationship between the NCS and the inventory level can be made even clearer by fitting a line based on a third order polynomial function through the plots. This function is represented by the black line in the graph 13-17.

Especially soybeans and copper obtains the familiar cubic curve that was proposed by Working in 1948, as the polynomial function explains nearly 40% of the NCS. As for corn and WTI the curve explains 19% and 24%, respectively. Visually these lines also offer a similar result as the one proposed by Working (1948).

The polynomial function fitted by the stock used to measure wheat only explained 11% of the NCS, by fitting the same third order polynomial function. By comparing the plot obtained from the wheat data set with the ones obtained by Joseph et al. (2011), it is possible to see that the plot diagram in figure 15 looks more similar to the one they obtained from using only Kansas wheat price and inventory. An explanation could be that the hard red winter wheat traded at KCBT constitutes a bigger part of the aggregated wheat stock used in this thesis.

Still, all the fitted curves in figure 13-17 proves to be decreasing as inventory goes down, confirming the same behavior as suggested by Working and Brennan.

6.4 Results from regression analysis on equation 9 and 12

The conducted regression analysis confirmed much of the behavior suggested by the theory of storage. To make the results simpler to read, a general interpretation of the parameters, their economical meaning, and a recap of their expected signs, will first be presented.

The inverse form of the β_1 parameters corresponding variable makes it a bit problematic to give an exact economical interpretation based on its magnitude. Thus, perhaps the most informal attribute, besides whether it is significant or not, is the sign of the parameter. A negative sign indicates that the NCS is an increasing concave function of the inventory level, capped by the constant term of the regression model. A positive sign would make it a decreasing convex function. Since the NCS is expected to be an increasing function of the inventory level, the estimated sign of β_1 is assumed to be negative.

Similar to β_1, the marginal effect of β_2 also depends on the level of its corresponding variable, due to its exponential form. Since the relative volatility term enters the model squared, its marginal effect on the NCS will change linearly with $2 * \beta_2 * V$ for every 1 unit change in the relative volatility. In conjunction to this, it should be mentioned that 1 unit increase in the relative volatility indicates that the spot price volatility becomes twice as large as the futures price volatility. That does not happen too often. The NCS is assumed to be a decreasing function of the spot price volatility making the expected sign of β_2 negative.

The interpretation of the β_3 parameter, measuring the effect of the capital cost, is on the other hand rather straight forward. The corresponding variable measures the percentage change in the capital cost, making β_3 the partial change in the NCS when the capital cost changes with 1%. The sign of β_3 is expected to be positive.

The β_4 parameter, corresponding to the relative inventory dummy variable, can be understood as the level effect on the NCS when the inventory is below its five year average value. Thus, β_4 is expected to be negative, since a current inventory level below its reference value should indicate an increased risk of stock outs.

The β_5 parameter measures the effect of a change in the net hedging pressure from long to short, and are expected to be negative in the case of a risk premium.

According to a Dickey-Fuller test and a Philips-Perron test, all the continuous variables included on the model are stationary processes.

In the tables presented below, α and $\beta_{1,2,3,4,5}$ are the parameters of the models. D_m (F) is the F-statistic obtained from testing whether the seasonally dummies are jointly different from zero. *F-value* is the combined F-statistic for the whole model.

All the t-values and corresponding p-values are calculated by using Newey-West standard errors with five lags, to ensure against heteroscedasticity and autocorrelation in the variables. R^2 is the coefficient of determination calculated with regular OLS standard errors.

OLS regressions are also preformed on sub-samples of the periods 1990-1999 and 2000-2012. The results from these regressions are included in the appendix.

Table 6: Results from OLS regression of equation 9 and 12 for Corn (1990-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
NCS $_{1-2}$									
Model 1	0,029***	-1117,38***	-0,005	0,004	-0,009***	-0,004***	-	3,96***	0,32
Model 2	0,031***	-2248,70***	-0,0006	-0,002	-0,006***	-0,005***	6,03***	6,54***	0,51
NCS $_{1-3}$									
Model 1	0,025***	-643,03***	-0,003***	0,0005	-0,008***	-0,006***	-	15,53***	0,29
Model 2	0,027***	-1468,18***	-0,001	-0,001	-0,004**	-0,006***	2,82***	5,97***	0,48
NCS $_{1-4}$									
Model 1	0,022***	-228,22**	-0,003***	-0,002	-0,006***	-0,007***	-	9,80***	0,36
Model 2	0,024***	-775,31**	-0,002***	-0,002	-0,002	-0,008***	4,20***	6,31***	0,51
NCS $_{1-5}$									
Model 1	0,019***	-182,28	-0,003***	-0,002	-0,003***	-0,007***	-	9,91***	0,37
Model 2	0,022***	-710,48***	-0,002***	-0,002	-0,002	-0,008***	3,79***	6,12***	0,52

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

Table 7: Results from OLS regression of equation 9 and 12 for Soybeans (1990-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
NCS $_{1-2}$									
Model 1	0,011***	-276,63***	-0,021***	0,005**	-0,005***	0,004***	-	27,36***	0,45
Model 2	0,017***	-623,02***	-0,002***	0,0003	-0,001	0,003	7,64***	35,58***	0,62
NCS $_{1-3}$									
Model 1	0,009***	-199,09***	-0,001	0,009**	-0,005***	0,002	-	9,12***	0,32
Model 2	0,016**	-447,11***	-0,001	-0,001	-0,003	0,001	5,24***	9,74***	0,52
NCS $_{1-4}$									
Model 1	0,006***	-85,51***	-0,001	0,001	-0,007***	0,001	-	8,02***	0,25
Model 2	0,015***	-294,52***	-0,001**	-0,002	-0,004***	-0,001	3,50***	8,95***	0,46
NCS $_{1-5}$									
Model 1	0,004***	-27,77	-0,001	-0,003**	-0,007***	-0,001	-	6,62***	0,26
Model 2	0,014***	-197,02**	-0,001**	-0,003**	-0,003***	-0,002	3,53***	5,32***	0,43
NCS $_{1-6}$									
Model 1	0,002***	-1,56	-0,001**	-0,005***	-0,006**	-0,002	-	6,31***	0,28
Model 2	0,010***	-120,90**	-0,001**	-0,004**	-0,003**	-0,002**	2,55***	4,43***	0,38
NCS $_{1-7}$									
Model 1	0,002***	-7,58	-0,001	-0,004**	-0,005***	-0,002**	-	5,98***	0,26
Model 2	0,010**	-129,28**	-0,001	-0,004***	-0,003***	-0,002***	1,80**	3,67***	0,36

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

Table 8: Results from OLS regression of equation 9 and 12 for Wheat (1990-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
NCS $_{1-2}$									
Model 1	0,021***	-311,11***	-0,001	0,004	-0,007***	-0,004***	-	6,50***	0,20
Model 2	0,027***	-641,61***	-0,001***	-0,0005	-0,007***	0,005	5,75***	7,80***	0,53
NCS $_{1-3}$									
Model 1	0,011***	-169,01***	-0,001***	0,002	-0,003**	-0,003***	-	8,28***	0,29
Model 2	0,013***	-322,26***	-0,001***	-0,001	-0,003**	0,002	5,81***	7,34***	0,59
NCS $_{1-4}$									
Model 1	0,011***	-135,51***	-0,001**	0,002	-0,004**	-0,004***	-	7,28***	0,21
Model 2	0,015***	-442,64***	-0,001**	-0,001	-0,003***	0,001	5,61***	8,63***	0,58
NCS $_{1-5}$									
Model 1	0,010***	-29,22	-0,002***	-0,001	-0,004***	-0,004***	-	6,76***	0,29
Model 2	0,015***	-422,00***	-0,001***	-0,002	-0,004***	-0,002**	5,28***	11,83***	0,59

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

Table 9: Results from OLS regression of equation 9 and 12 for WTI (1990-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
NCS $_{1\text{-}2}$									
Model 1	0,15***	-40,16***	-0,022***	-0,001	-0,001	-0,005***	-	12,69***	0,33
Model 2	0,18***	-49,35***	-0,015**	0,001	-0,002	-0,008***	1,17	5,38***	0,40
NCS $_{1\text{-}3}$									
Model 1	0,13***	-36,28***	-0,009***	-0,001	-0,001	-0,004	-	28,30***	0,37
Model 2	0,15***	-44,09***	-0,006***	-0,002	-0,001	-0,007	0,47	11,90***	0,43
NCS $_{1\text{-}6}$									
Model 1	0,10***	-29,80***	-0,002***	-0,005	-0,001	-0,004	-	25,31***	0,40
Model 2	0,12***	-36,11***	-0,002***	-0,004	-0,001	-0,005***	1,06	15,33***	0,47
NCS $_{1\text{-}9}$									
Model 1	0,08***	-24,16***	-0,002***	-0,005	-0,001	-0,003	-	24,58***	0,43
Model 2	0,09***	-29,46***	-0,001***	-0,005	-0,001	-0,004***	1,05	12,79***	0,48
NCS $_{1\text{-}12}$									
Model 1	0,06***	-20,28***	-0,001***	-0,005	-0,001	-0,002	-	27,53***	0,45
Model 2	0,08***	-24,99***	-0,001***	-0,004	-0,0003	-0,003**	1,21	12,24***	0,49

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

Table 10: Results from OLS regression of equation 9 and 12 for Copper (2001-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 {V_t}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
NCS $_{1-2}$									
Model 1	0,012***	-41,63***	-0,011***	-0,002**	-0,002**	-0,001	-	23,95***	0,59
Model 2	0,001***	-46,06***	-0,011***	-0,002**	-0,002**	-0,001	1,33	29,81***	0,64
NCS $_{1-3}$									
Model 1	0,004	-42,16***	-0,002	-0,002**	-0,003***	-0,002	-	10,91***	0,53
Model 2	-0,006	-44,78***	-0,002	-0,002**	-0,003**	-0,001	1,41	15,87***	0,58
NCS $_{1-4}$									
Model 1	0,003	-43,63***	0,001	-0,001	-0,003**	-0,002**	-	9,94***	0,52
Model 2	-0,009	-45,75***	-0,002	-0,002**	-0,003***	0,002	1,69	10,25***	0,56
NCS $_{1-5}$									
Model 1	0,002	-42,15***	-0,001	-0,001	-0,003**	-0,003**	-	11,41***	0,48
Model 2	-0,009	-44,34**	-0,002	-0,001	-0,003**	-0,002**	1,51	9,87***	0,52

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

The results posted above verify that both models are statistically significant, referring to their F-values. The R^2 values are ranged from 0,17 to 0,61. Focusing on the three agricultural commodities, the seasonal dummies increased the explanatory power of the model significantly, indicating that the NCS for these commodities are affected by seasonal fluctuations.

This can also be seen from the significant F-statistics of the seasonal parameters for corn, soybeans and wheat. This statistic was on the other hand not significant for WTI and copper, indicating that the NCS for these commodities are not affected by any seasonally based fluctuations. This is in accordance with the findings of Symeonidis (2012), pointing out how a seasonally constrained production affects both the present and the future valuation of the commodity.

The inventory's effect on the NCS satisfies the expectations drawn from the theory of storage. All the significant inventory parameters yielded negative values, signifying that the NCS is an increasing non-linear function of the inventory.

The significant values of the β_2 parameters proved to be in accordance with the hypothesis of Samuelson, saying that relatively high spot price volatility can be related to low inventory levels, and thereby also negativity in the NCS. The negative magnitudes of the parameter verify that the NCS decreases when spot price volatility increases relative to the futures price volatility.

The parameter measuring the effect of changes in the capital cost offered a bit more mixed results, being both positively and negatively significant for soybeans and copper. This result appears as a bit surprising since this variable was expected to have a negative effect on the convenience yield.

The net hedging pressure proved to be statistically significant for several contract spreads, indicating that negativity in the NCS might also be linked to a risk premium. This result will alongside with the others be elaborated further in chapter 7.

6.5 *Calculating critical inventory values*

A nice attribute given by an inverse form in a regression model, is the possibility to estimate the critical value of the independent variable that yields a zero value for the dependent variable. This number is in this thesis especially interesting, being the estimated value of the inventory that yields a NCS equal to zero.

The critical inventory value can be calculated simply by dividing the absolute value of the estimated parameter on the constant term of the model (Gujarati and Porter 2009) [19]. By running the single regression models,

$$NCS_{1-2,t} = \alpha + \beta_1 I_t^{-1} + \varepsilon_{1,2,t} \tag{14}$$

and then calculate the value of $\frac{\alpha}{\beta_1}$, the critical values of the inventory can be estimated. A single regression model is used to avoid noise in the intercept term.

Table 11: Estimated critical inventory values

Commodity	Estimated Critical Inventory Value	Estimated numbers of backwardation	Actual numbers of backwardation	Precision
Corn $_{1-2}$	57 863	43	48	81 %
Soybeans $_{1-2}$	26 332	131	109	71 %
Wheat $_{1-2}$	21 267	38	59	74 %
WTI $_{1-2}$	328	140	125	68 %
Copper $_{1-2}$	174 844	104	82	51 %

Table 11 presents the estimated critical inventory value, calculated from the parameters of the NCS_{1-2} in equation 14. The measurement unit of the inventory variables is thousand metric tons for corn, wheat and soybeans, million barrels for WTI and short tons for copper. Estimated numbers of backwardation is the number of month the actual inventory level was below the critical value, thereby predicting backwardation, while Actual numbers of backwardation is the true number of month the NCS offered negative values. Precision is the percentage of times the estimated critical inventory value correctly predicted the real market state.

[19] $NCS = \alpha - \beta\frac{1}{I} = 0 \rightarrow \frac{\alpha}{\beta} = \frac{1}{I} \rightarrow I = \frac{\beta}{\alpha}\ when\ NCS = 0$

As can be seen from table 9, all estimated inventory values predicted the correct market state more than 50% of the times for all the commodities, and up to 80% for corn. This demonstrates how the market perception of the critical inventory level has been fairly stable for corn, soybeans, wheat and WTI over the time period 1990-2012.

6.6 Results from testing for structural break after 1999

To examine whether the increase in speculative positions during the last decade has changed the influence of the variables by any significant amount, a test for structural changes after 1999 is conducted. Pure speculators have no real use for the physical commodity, and should thereby not include this variable in their pricing models. Thus, an increase in speculative positions should change the behavior of the NCS, making it less dependent on the inventory variable, and possibly more dependent on the net hedging pressure.

A Chow test was found to be appropriate to test this hypothesis, as the error variances of the sub samples are not significantly different from each other. Copper was not included due to the small data sample. The Chow F-statistics provided evidence for a structural break between after 1999 for both models and nearly all NCS variables. The results from the Chow test are included in the appendix.

The dummy test for a structural break was also conducted on the two models in equation 9 and 12, by running the model presented in equation 13. This test makes it possible to see how each specific variable is affected by the potential break. In the following tables, significant values signify a structural break in the respective parameter. The F-values are derived from a joint test of γ_1 and $\omega_{1,2,3,4,5}$ all equal to zero. A significant F-value indicates an overall structural break in the model.

Table 12: Dummy variable test for structural break after 1999 Corn							
	γ_1	ω_1	ω_2	ω_3	ω_4	ω_5	F-test
$NCS_{1\text{-}2}$							
Model 1	0,010	1074,57***	-0,005	-0,003	0,006	-0,003	6,53***
Model 2	-0,032	638,51	-0,002	0,038***	-0,003	-0,004	1,37
$NCS_{1\text{-}3}$							
Model 1	-0,003	405,42*	-0,006***	0,008	0,006	-0,002	6,79***
Model 2	-0,034**	430,57	-0,008***	0,048***	-0,001	-0,004	4,05***
$NCS_{1\text{-}4}$							
Model 1	-0,005	65,86	-0,004***	0,014*	0,003	-0,002	8,21***
Model 2	-0,020	-83,36	-0,005***	0,035***	-0,002	-0,003	3,64***
$NCS_{1\text{-}5}$							
Model 1	-0,006	112,76	-0,002	0,012***	-0,002	-0,006	7,87***
Model 2	-0,014	-275,42	-0,002**	0,025***	0,001	-0,002	2,91***

Significant parameters are marked with ** and * for 5% and 1% significance level, respectively.** $\boldsymbol{\gamma_1 = change\ in\ intercept,\ \omega_1 = change\ in\ \frac{1}{I}, \omega_2 = change\ in\ V^2, \omega_3 = change\ in\ \Delta CC, \omega_4 = change\ in\ D_{invt.}\ and\ \omega_5 = change\ in\ D_{NHP}}$

Table 13: Dummy variable test for structural break after 1999 Soybeans							
	γ_1	ω_1	ω_2	ω_3	ω_4	ω_5	F-test
$NCS_{1\text{-}2}$							
Model 1	0,013	90,98**	-0,011***	-0,001	-0,0002	-0,007	2,55**
Model 2	-0,002	681,50***	-0,008***	-0,003	-0,007**	-0,002	8,01***
$NCS_{1\text{-}3}$							
Model 1	0,004	120,34**	-0,005***	-0,013	-0,001	-0,006	2,80**
Model 2	-0,002	533,98***	-0,004***	-0,005	-0,006	-0,003	4,27***
$NCS_{1\text{-}4}$							
Model 1	0,002	100,02**	-0,003***	-0,017	-0,001	-0,005	3,28***
Model 2	0,001	423,13***	-0,002**	0,007	-0,006**	-0,004	4,28***
$NCS_{1\text{-}5}$							
Model 1	0,003	59,97*	-0,002***	-0,008	-0,001	-0,004	3,09***
Model 2	0,0001	359,25***	-0,002**	0,015	-0,006**	-0,003	4,60***
$NCS_{1\text{-}6}$							
Model 1	0,001	53,08**	-0,001**	-0,012**	-0,002	-0,002	3,64***
Model 2	-0,0007	253,86***	-0,0005	0,014	-0,005	-0,001	3,64***
$NCS_{1\text{-}7}$							
Model 1	0,002	36,10	-0,001***	0,002	-0,002	-0,003*	3,57***
Model 2	-0,002	259,02***	-0,001***	0,015	-0,004**	-0,002	4,41***

Significant parameters are marked with ** and * for 5% and 1% significance level, respectively.** $\boldsymbol{\gamma_1 = change\ in\ intercept,\ \omega_1 = change\ in\ \frac{1}{I}, \omega_2 = change\ in\ V^2, \omega_3 = change\ in\ \Delta CC, \omega_4 = change\ in\ D_{invt.}\ and\ \omega_5 = change\ in\ D_{NHP}}$

Table 14: Dummy variable test for structural break after 1999
Wheat

	γ_1	ω_1	ω_2	ω_3	ω_4	ω_5	F-test
NCS$_{1-2}$							
Model 1	0,018	405,96***	-0,011**	-0,017***	0,006**	-0,010***	21,42***
Model 2	0,006	876,24***	-0,008	0,023	0,001	-0,011***	8,48***
NCS$_{1-3}$							
Model 1	0,005	202,16***	-0,002	-0,002***	0,004***	-0,005***	24,78***
Model 2	0,002	400,47***	-0,001	0,012	0,002	-0,005***	8,78***
NCS $_{1-4}$							
Model 1	0,01***	71,54	-0,002***	-0,018***	0,007***	-0,005**	14,78***
Model 2	0,007	286,49***	-0,001***	0,018***	0,004**	-0,005**	7,39***
NCS $_{1-5}$							
Model 1	0,011	-96,55	-0,002***	0,015	0,008***	-0,002	11,29***
Model 2	0,008*	157,47	-0,002***	0,018	0,004**	-0,002	7,03***

Significant parameters are marked with ** and * for 5% and 1% significance level, respectively.** $\boldsymbol{\gamma_1 = change\ in\ intercept,\ \omega_1 = change\ in\ \frac{1}{I}, \omega_2 = change\ in\ V^2, \omega_3 = change\ in\ \Delta CC, \omega_4 = change\ in\ D_{invt.}\ and\ \omega_5 = change\ in\ D_{NHP}}$

Table 15: Dummy variable test for structural break after 1999
WTI

	γ_1	ω_1	ω_2	ω_3	ω_4	ω_5	F-test
NCS$_{1-2}$							
Model 1	0,010**	1,05	-0,013	-0,004	-0,008*	-0,008	6,67***
Model 2	-0,04	15,08	-0,02**	-0,003	-0,007	-0,012**	3,92***
NCS$_{1-3}$							
Model 1	-0,017**	4,72	0,001	-0,008	-0,008**	-0,006	6,35***
Model 2	-0,06	17,27	-0,004	-0,009	-0,006	-0,009**	3,44***
NCS $_{1-6}$							
Model 1	-0,027**	6,49	0,002**	-0,01	-0,005**	-0,004	8,49***
Model 2	-0,06**	16,53**	0,001	-0,01	-0,004	-0,005	4,90***
NCS $_{1-9}$							
Model 1	-0,03*	8,45	0,001**	-0,01	-0,004*	-0,002	7,01***
Model 2	-0,06**	16,95**	0,001	-0,01	-0,003	-0,004	4,77***
NCS $_{1-12}$							
Model 1	-0,03**	9,78	0,005	-0,009	-0,003	-0,002	5,62***
Model 2	-0,06***	17,13**	0,0001	-0,008	-0,003	-0,004	4,35***

Significant parameters are marked with ** and * for 5% and 1% significance level, respectively.** $\boldsymbol{\gamma_1 = change\ in\ intercept,\ \omega_1 = change\ in\ \frac{1}{I}, \omega_2 = change\ in\ V^2, \omega_3 = change\ in\ \Delta CC, \omega_4 = change\ in\ D_{invt.}\ and\ \omega_5 = change\ in\ D_{NHP}}$

The F-statistics presented in table 12-15 indicates the same conclusion as the Chow test, namely that there has been a structural break in the parameters magnitude between 1990-1999 and 2000-2012. As can be seen all the commodities experienced a significant change in the effect of the inventory variable, indicating a valuation of the commodity price that is less based on fundamentals like the inventory level.

7 Discussion of results

7.1 The average NCS and the Convenience yield

The NCS for all five commodities seems to include a convenience yield in the period 1990-2012. In conjunction with this, it should be mentioned that the estimated storage rates used to calculate the convenience yield in table 3 are somewhat inaccurate. They are also postponed to the quite strong assumption of being a stable proportion of the spot price over time. Still, the point here is rather to show whether a convenience yield actually is present, and not to estimate its exact value.

The decreasing NCS values for corn, wheat and WTI proves that the convenience yield is an increasing function of time to delivery. The one year term structure of the average convenience yield has increased almost linearly for corn, while it holds a more upward sloping concave structure for Wheat and WTI. These results demonstrate that the convenience yield is an accumulating process of time to delivery, indicating a growing intrinsic value of having the physical commodities at hand. Nonetheless, the concave structures of wheat and WTI, proves that it is not necessarily a linear relationship. The same relationships are also present when focusing on subsamples from 1990-1999 and 2000-2012. A convenience yield that increases with time to delivery, was also found in studies by Milonas and Henker (2001) and Caumon and Bower (2004).

A convenience yield is also found from the average NCS for soybeans, but this yield does not seem to alter very much as time to delivery increases. An explanation to this could be that soybeans to some extend are more perishable than the other commodities included in this study. The low storability causes the convenience yield not to accumulate, since the commodity cannot be carried over a longer period of time.

Copper also proved to be affected by a convenience yield. Comparing the estimated storage cost with the NCS demonstrates that copper holds the largest proportionate convenience yield of all the five commodities. Since copper is a relatively cheap commodity, this is not too surprising. The NCS variable alters very little between each contract spread, indicating that the convenience yield on average do not accumulates over time.

The maximum NCS values confirm that the futures price tends to be constrained by the cash and carry arbitrage theory, considering that the max values seem to be suppressed by their estimated storage costs. As mentioned in chapter 5, WTI proves to be an exception.

7.2 Empirical Working curves

The empirically fitted Working curve for the five commodities show that the NCS tends to become negative as inventory goes down, indicating that inventory is stored at a negative return. The estimated curves are graphically in accordance with the curves obtained by Joseph et.al. (2011).

To find out whether commodities are stored at a negative return, Franken et al. 2009 applies the perhaps most reasonable method of them all, by simply asking inventory holders. Through a series of interviews with elevator managers, they found that commodities are often stored at a negative return. The main explanation given by the elevator managers, was to meet previous commitments of delivery.

Revoredo (2000) points to the importance of distinguishing between the different market participant's incentives to store commodities. He simulates a theoretical model focusing on the relationship between processors and speculators[20]. Through this model he shows that it is the combined positions of these two market participants that results in the concave relationship between the price spread and the inventory level.

This proves that even if a Working-like relationship is present in the commodity markets, it is important to also consider the heterogeneity of the market agents when explaining the seemingly irrational act of holding physical stocks during backwardation.

7.3 Results from regression analysis of equation 9 and 12

The primary goal of the regression analysis is to examine the behavior of the convenience yield based on the relationship suggested by the theory of storage. Thus, the most central argument in this case is the relationship between the NCS and the inventory level

[20] The graphs presented by Revoredo (2000) can be found in the appendix.

The results from the OLS regression verify that the link between the inventory level and NCS is indeed a statistically significant relationship. The negative sign on the β_1 parameter also confirms that the NCS is an increasing function of the inventory level. This is in accordance with the findings of Carbonez et al. (2010), Duan and Lin (2010) and Symeonidis et al. (2012), clearly indicating that the prices of storable commodities are affected by fundamental factors like the inventory level.

An important result related to how the market consider the inventory level, can be seen by focusing on the β_1 parameter for the three agricultural commodities in model 1. When the variables are not seasonally adjusted, the last contract of the agricultural commodities tends to become insignificant. Lautier (2005) points out how agricultural futures contracts are priced differently, depending on their delivery date relative to the harvest cycle. More specific, the convenience yield of contracts with delivery after the next harvest should not be affected by the inventory level before that respective harvest period. The insignificant effect on the inventory of the long term NCS indicates that the market also holds the same mindset.

The actual magnitude of the inventory variable offers little intuitive information due to the functional form of the models. Still, the elasticity of the variable points out some important characteristics for each of the commodities. The inventory elasticity is calculated by using average values of the NCS and the inventory level alongside with the β_1 parameter form Model 2. The calculated values are reported in table 16. As can be seen from the table, all the commodities, except copper, hold an elastic relationship between the NCS and the inventory.

Table 16: Average inventory elasticity* for Corn, Soybeans, Wheat, WTI and Copper based on model 2

NCS_{1-n}	**Corn**	**Soybeans**	**Wheat**	**WTI**	**Copper**
NCS_{1-2}	|3,16|	|6,47|	|3,16|	|73,39|	|0,17|
NCS_{1-3}	|2,34|	|4,39|	|6,81|	|46,97|	|0,20|
NCS_{1-4}	|1,57|	|3,06|	|7,98|	-	|0,22|
NCS_{1-5}	|1,91|	|2,19|	|9,08|	-	|0,21|
NCS_{1-6}	-	|1,45|	-	|26,93|	-
NCS_{1-7}	-	|1,53|	-	-	-
NCS_{1-9}	-	-	-	|20,02|	-
NCS_{1-12}	-	-	-	|16,72|	-

$*|e| = \frac{\beta_1}{\bar{I} * \overline{NCS}}$

WTI is clearly the most sensitive of the five commodities, indicating that a small change in the storage level will cause a large change in the NCS. A possible explanation to this could be

crude oil's critical position as a direct or indirect input factor in many industries, making the intrinsic value of the commodity more sensitive to fluctuations in the inventory level.
A second explanation could be that the inventory level of WTI is more stable, compared with the other commodities. By comparing the inventory's coefficient of variation for the five commodities, it is possible to see that WTI clearly stands out holding the smallest coefficient[21]. Thus, due to a more stable supply, even a small change in the inventory might appear as unexpected, generating a bigger effect on the convenience yield.

Copper inventory proved to be inelastic for every contract spread, indicating that a 1% changes in the copper inventory causes less than 1% changes in the NCS. As in the opposite of WTI, this could be due to the extremely high coefficient of variation in copper inventory, making the NCS less responsive to small fluctuations in the storage level. As explained in chapter 3, metals are known to not hold any significant evidence for seasonality. Hence, seasonal fluctuations in supply or demands seem to make the NCS more sensitive to changes in the inventory.

The NCS of the agricultural commodities also proved to be elastic considering changes in the inventory level. The elastic relationship between the NCS and the inventory level, combined with the significant estimated parameters, indicates that the relationship proposed by the theory of storage seems to be present.

The effect of the spot price volatility relative to the futures price volatility yielded significant parameters for most of the models and contract spreads. As expected, all of the significant parameters are negatively correlated with the NCS. This suggests that more price uncertainty in the spot market, relative to the amount in the futures market, makes the convenience yield to increase.

Pindyck (2001) emphasize that a change in net demand caused by a decrease in supply, very often results in increasing spot price volatility. This indicates that correlation between the NCS and the relative spot price volatility can be due to a shared correlation with the inventory variable. Nevertheless, the partial effect of the relative spot volatility is significant, also when

[21] See table 2

controlling for the effect of the inventory level, suggesting that there is a direct link between volatility in the spot price and the NCS.

The variable measuring the change in capital costs gave some mixed results compared with the expectation. Measuring the true capital cost is problematic since this can vary between market participants. The insignificant results could be the consequence of a measurement error, indicating that the market discounts its capital with a different rate than the three months Treasury bill. Duan and Lin (2010) also used the three month Treasury bill rate as a proxy for capital costs and obtained similar insignificant results for soybeans, corn and crude oil.

Another explanation could be found in the method used to calculate the capital cost in this thesis. Both the capital cost and the NCS are here defined as functions of the spot price. This may generate a two way effect that cancel each other out, as the NCS is a decreasing function of the spot price and capital cost is a decreasing function of the spot price. This could also explain why some of the β_3 parameters offer a negative effect on the NCS.

A third possibility could of course be that the NCS is actually not significantly affected by the capital cost. Still, this does not explain the negative values found in some of the parameters.

The relative inventory's effect, measured by β_4 proved to be mainly statistically significant for corn, soybeans, wheat and copper. The negative magnitude of the parameter signifies that the NCS decreases in periods when the inventory is below its five year average, indicating that the markets evaluate the inventory level relative to its past levels and not only the current level.

On the other side the parameter was not significant for WTI. As WTI is a continuously extracted commodity holding a relatively stable supply, this is also to be expected. A more stable supply should cause past values of inventory to become less important, when people consider shortage of supply.

The parameter measuring the effect of a change in the net hedging pressure proved to be negative and significant for several NCS spreads, verifying that negativity in the basis also can be linked to a potential risk premium. A similar result concerning the crude oil and the natural gas market, is proposed by Dinceler et.al. (2005).

In this thesis, the NCS for corn, wheat and WTI is significantly affected by a change in the hedging pressure for all contract spreads in both models using data from 1990-2012. This demonstrates how short hedgers offer a discounted futures price in times were the commercial net hedging pressure is short.

The effect of a switch in the net hedging pressure for soybeans is found to be insignificant for most of the contract spreads. Still, this does not necessarily means that there is no risk premium in the market. Numbers from the CFTC show the commercial hedging pressure for soybeans was net short 75% of the months, from 03.1990-12.2012. As can be seen from table 5, the commodity also experienced backwardation on average, for all the included contract spreads. According to these numbers there are reasons to believe that a risk premium do exists in the soybean market, despite of the insignificant effect of a switch in the commercial net hedging pressure.

7.4 Structural breaks after 1999

Both a Chow test and a dummy variable test for structural breaks confirm that the models yield different parameters in each of the two sub-samples. There can be many reasons for this break, and the change in investor activity can only be regarded as one of them. Nevertheless, the convenience yield is a variable that is only relevant for a certain group of market agents, namely those who sees an intrinsic value in the physical good. As speculators are assumed to have no real interest in the physical commodity, an increase in speculative positions should also have altered the pricing of the commodities.

Since model 1 and model 2 aims to explain the variation in the convenience yield, it is expected that a change in the overall markets apprehension of the concept also should alter the models parameters. If an increasing amount of speculation has altered the behavior of the convenience yield, there should first of all have been a change in the effect of the inventory variable, as an inventory related valuation of the convenience yield is more relevant for producers and processors. More specifically, the effect of the inventory variable should decrease after 1999, as a result of more speculative positions.

The parameters presented in table 10-13 represent the magnitude of change in the original parameters of equation 9 and 12 (Model 1 and Model 2). The values in table 10 demonstrate that the structural break after 1999 for corn is primarily caused by a change in the effect of the relative spot price volatility. The result indicates that the effect of the relative spot price volatility has increased in 2000-2012, as the parameter has become more negative. This could possibly indicate that hedging with physical inventories has become more common in the last decade, which is also expected considering the large increase in the spot price volatility. Still, the overall result for corn does not offer any strong evidence for a change in the valuation of the convenience yield caused by more speculation.

The only exception for corn was the NCS_{1-2}. For this variable, the inventory did experience a significant alteration in its effect after year 2000. In conjunction with this, figure 18 presents two Working curves for the predicted values of the NCS_{1-2} for corn, based on changes in the inverse inventory variable for 1990-1999 and 2000-2012.

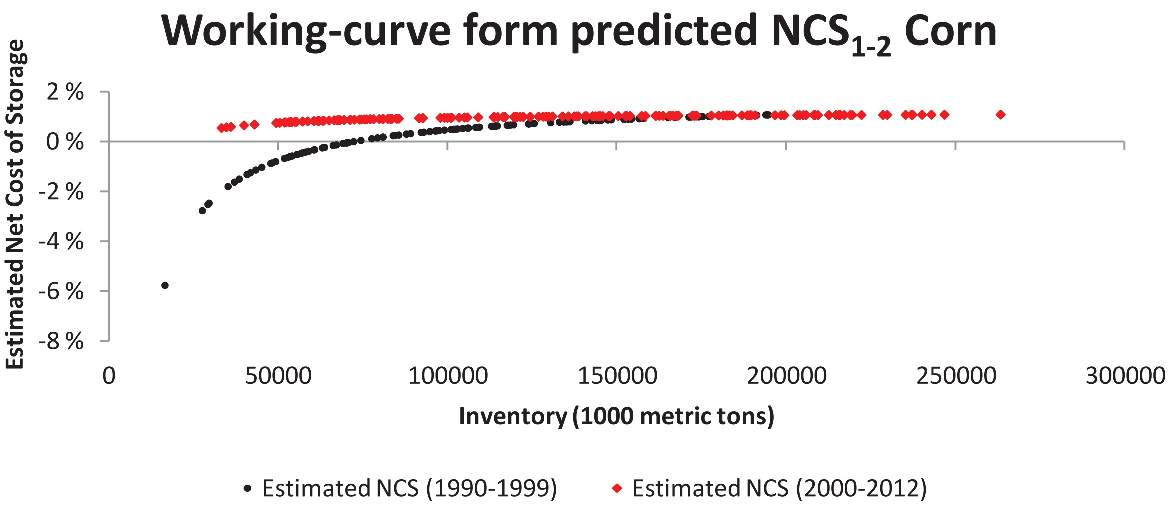

Figure 18: Predicted Working curve for corn. NCS is estimated by the inverse inventory level in the two sub samples 1990-1990 (black plots) and 2000-2012 (red plots). The estimation regression is: $\boldsymbol{NCS_{1-2,t} = \alpha_t + \beta_1 I_t^{-1} + \beta_2 D_{1\,if>1999,t} + \beta_3\left(I_t^{-1} * D_{1\,if>1999,t}\right) + \varepsilon_t}$, where $\boldsymbol{D_{1\,if>1999,t}}$ is a dummy equal to 1 for all observations after 1999. Rest of notation is similar to equation 8 and 9.

From figure 18, it becomes clear that the estimated NCS_{1-2} is affected quite differently by the inventory variable after 2000, indicating a structural break. By comparing this figure with

Revoredo's Working curves[22], it is possible to see that the curve represented by the red dots looks more similar to the one he estimates for speculators only.

The results for soybeans, posted in table 12, demonstrate that there has been a significant drop in the inventory's effect on the NCS after 1999. This decrease in the effect of the inventory variable could have been caused by the market finding less weight on fundamental factors like stock levels. The decreasing effect of the inventory variable is especially strong for the NCS_{1-5}, NCS_{1-6} and NCS_{1-7}. Similar to corn, soybeans also experienced a break in the effect of the relative spot price volatility.

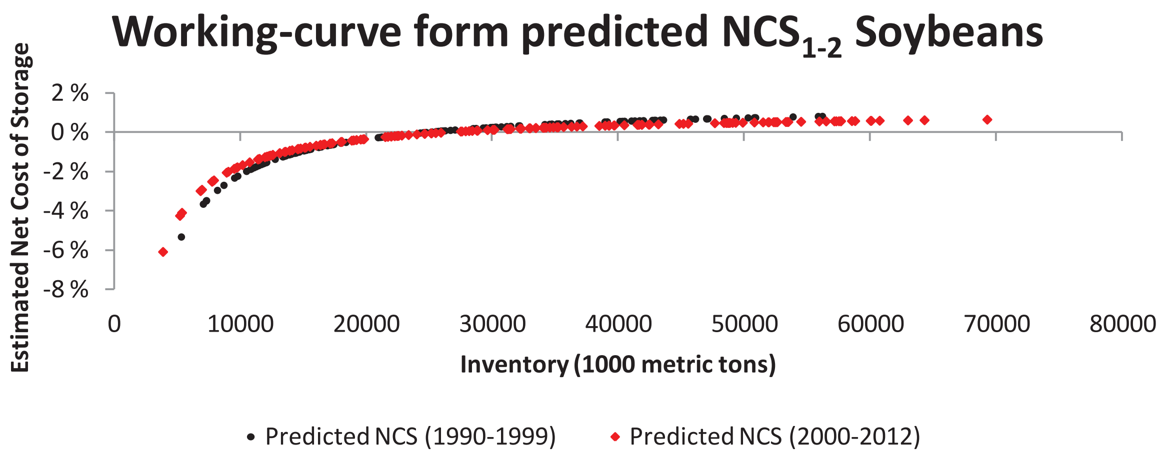

Figure 19: Predicted Working curve for soybeans. NCS is estimated by the inverse inventory level in the two sub samples 1990-1990 (black plots) and 2000-2012 (red plots). The estimation regression is: $\boldsymbol{NCS_{1-2,t}} = \boldsymbol{\alpha_t} + \boldsymbol{\beta_1 I_t^{-1}} + \boldsymbol{\beta_2 D_{1\,if\,>1999,t}} + \boldsymbol{\beta_3}(\boldsymbol{I_t^{-1}} * \boldsymbol{D_{1\,if\,>1999,t}}) + \boldsymbol{\varepsilon_t}$, where $\boldsymbol{D_{1\,if\,>1999,t}}$ is a dummy equal to 1 for all observations after 1999. Rest of notation is similar to equation 8 and 9.

Figure 19 proves that the soybean inventory's effect of the NCS_{1-2} did not alter much after 1999.

The structural break found in the models for wheat is caused by both a significantly decrease in the inventory's effect and a significantly increase in the effect of the net hedging pressure. This alteration point towards that increasing speculative activity, could have affected the valuation of the convenience yield. Wheat does also experience a structural break in the relative spot price volatility, signifying that the effect of the variable increased in the last decade, in accordance with corn and soybeans.

[22] These curves are included in the appendix

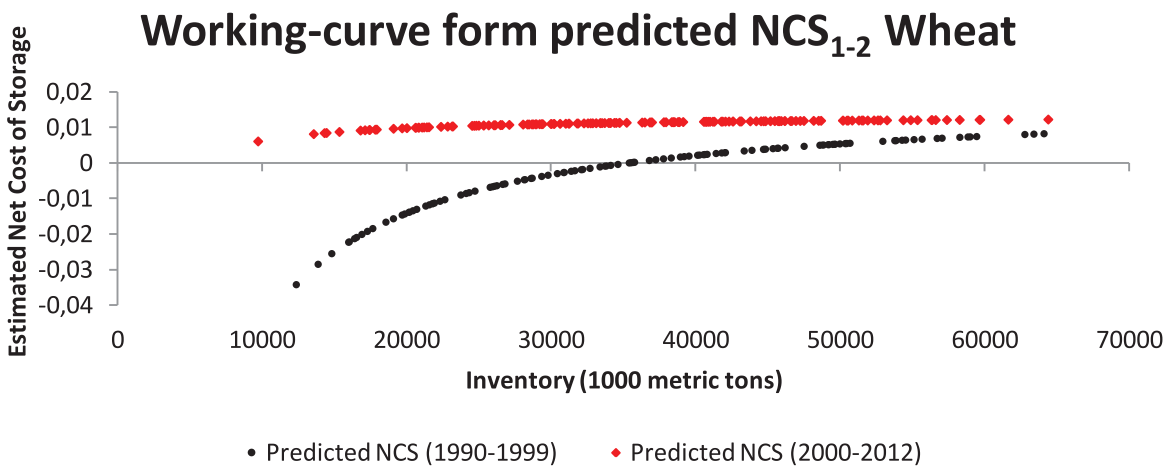

Figure 20: Predicted Working curve for wheat. NCS is estimated by the inverse inventory level in the two sub samples 1990-1990 (black plots) and 2000-2012 (red plots). The estimation regression is: $\boldsymbol{NCS_{1-2,t}} = \boldsymbol{\alpha_t} + \boldsymbol{\beta_1 I_t^{-1}} + \boldsymbol{\beta_2 D_{1\,if>1999,t}} + \boldsymbol{\beta_3}(\boldsymbol{I_t^{-1}} * \boldsymbol{D_{1\,if>1999,t}}) + \boldsymbol{\varepsilon_t}$, where $\boldsymbol{D_{1\,if>1999,t}}$ is a dummy equal to 1 for all observations after 1999. Rest of notation is similar to equation 8 and 9.

Figure 20 depicts how wheat experiences a change in the relationship between the NCS and the inventory level after year 1999. The estimated Working curves for wheat look similar to the ones obtained for corn, predicting a pattern that reflects an increase in speculative positions.

For WTI the results from table 15 are more unclear. The Commodity did experience a structural break in the overall model for all the NCS spreads, but there is no systematic pattern in how the variables change. This result indicates that the changes in the WTI parameters are more likely to be caused by other incidents than a change in the market's valuation of the convenience yield.

The WTI Working curves based on the predicted NCS tends to look like the curves Revoredo obtains for the market only consisting of processors. This indicates that a possible increase of speculative positions in the WTI market did not affect the relationship between the convenience yield and the inventory level.

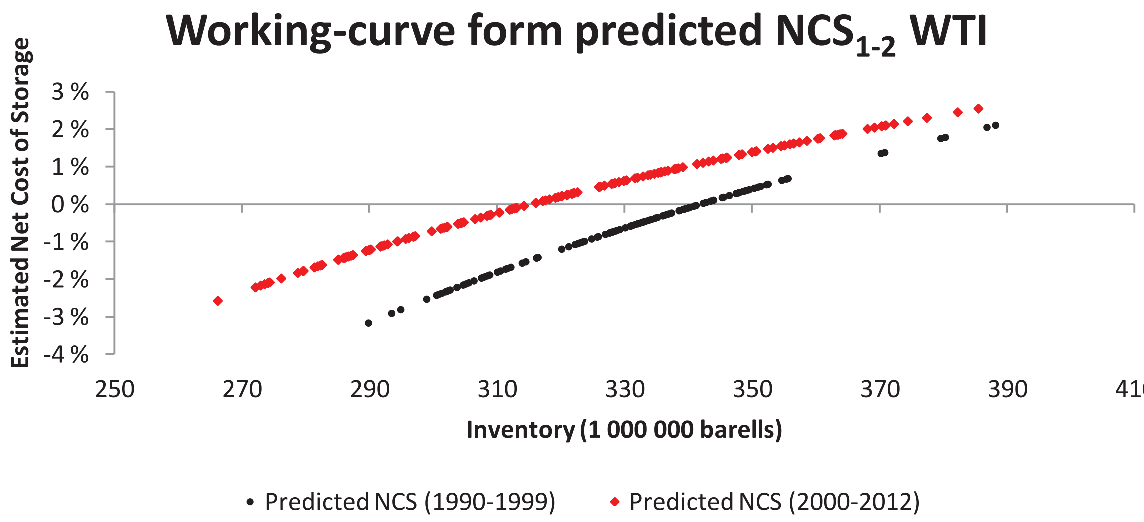

Figure 21: Predicted Working curve for WTI. NCS is estimated by the inverse inventory level in the two sub samples 1990-1990 (black plots) and 2000-2012 (red plots). The estimation regression is: $\boldsymbol{NCS_{1-2,t} = \alpha_t + \beta_1 I_t^{-1} + \beta_2 D_{1\,if>1999,t} + \beta_3\left(I_t^{-1} * D_{1\,if>1999,t}\right) + \varepsilon_t}$, where $\boldsymbol{D_{1\,if>1999,t}}$ is a dummy equal to 1 for all observations after 1999. Rest of notation is similar to equation 8 and 9.

The patterns presented in figure 18-21 can also be seen in the empirical Working curves based on actual data from the sub samples. These plots can be found in the appendix. Especially the empirical Working curves for wheat and corn shows similar patterns as the ones estimated above. The low explanatory power of the 2000-2012 curves for corn and wheat signifies that increasing speculative positions potentially weakens the link between the NCS and the inventory level.

Table 17 presents the percentage number of backwardation in the two periods. As can be seen, especially corn and wheat experienced far less backwardation in the last decade compared with the previous decade. This was also the case for soybeans and WTI, although not to the same extend as corn and wheat.

Table 17: Percentage amount of backwardation in 1990-1999 and 2000-2012

Commodity	1990-1999	2000-2012
Corn	29 %	9 %
Soybeans	42 %	37 %
Wheat	42 %	5 %
WTI	57 %	36 %

On the other hand, the coefficient of variation of the inventory does not change by much between the two time periods, indicating that the insecurity linked to the inventory level should have been approximately the same in the two time periods. This demonstrates how the decrease in backwardation may have been caused by market participants applying a more speculative pricing approach, giving less value to owning the physical commodity.

7.5 The Convenience Yield and Behavioral Economics

The working curves presented in chapter 6 signifies that commodities are being stored despite negative return to storage. This has proven to be an empirical fact, and is not necessarily caused by aggregation problems or other measurement errors (Carter & Giha, 2007; Joseph et al., 2011).

Yoon and Brorson (2002) try to explain this seemingly irrational behavior through theories drawn from the field of behavioral economics. They find that regret, overconfidence and anchoring offer possible explanations to why some agents choose to store inventory at a negative return. These are all behavioral factors based on human emotions rather than simple utility maximizing.

As emphasized by Revoredo (2000), there is no unifying explanation to why heterogeneous market agents choose to hold inventory in inverted markets. Thus, the best approach is to discuss this issue for each market participant's case by case. By using the same classification as given in chapter 2, the market participants will be defined as producers, processors and speculators.

A pure speculator defined as agents with no real interest in the commodity neither as an output nor as an input, can be assumed not to hold any physical commodities. These market agents are rather known to hold different derivatives reflecting the movements of the commodity price. In this way, the speculator avoids handling costs and other practical challenges linked to physical storage of commodities. In this regard, keeping physical stocks can be seen as an irrational investment by a pure speculator. Speculative stocks do indeed exist, but they are for all practical reasons assumed to be held by producers and processors. Consequently, the scenario of pure speculators holding physical stocks is not included in this discussion.

Producers:

The producers are naturally defined as those who manufacture the raw commodity. A producer is for example a farmer or a copper mine. Their economical incentive comes from the ability to produce the commodity at a lower cost than the market is willing to pay. Thus, a profit maximizing producer should always try to sell the output at the highest price achievable. In this sense, a producer has no particular economical incentives to store the commodity at a loss.

Nevertheless, statistics from the USDA show that the on-farm storage level for the period 1990-2012 never reaches zero, despite several occasions of negative NCS. This could naturally be caused by fundamental factors like changes in the commodity grade, due to decay, or business related issues like delivery problems. Still, Yoon and Brorson point out that this could also be caused by the producer being overconfident in his or hers own predictions of the market price, believing that an even better price can be achieved in the future. This could lead the producers to hold on to the inventory, regardless of a negative return to storage (Kahneman & Riepe 1998; Yoon & Brorsen 2002).

Another explanation is the anchoring effect. An anchor could make some producers reluctant to depart from long term strategies, despite of new market information. For example, a corn producer following a long term strategy of selling out inventory as September futures, would choose to keep the inventory in stock, despite backwardation in June and July. In conjunction with this, an additional explanation could be that a more active trading strategy also comes at a higher financial cost (Yoon & Brorsen, 2002).

An additional example of an anchor could be the producer's reference price. Reference prices can come from different sources like other commodity prices, last month's price, or the price of the corresponding month last year. These references can also be connected to overconfidence. The reference price might affect the producer's willingness to accept, indicating that they will store commodities at a negative return to storage, as their asking price is not in accordance with the market price.

Processors:

Processors can be defined as those who make use of the commodity as an input in a production process. By defining the convenience yield as an excess value derived from the intrinsic utility of the commodity, processors can be seen as the driving force behind backwarded prices.

From a processors point of view, storing inventory can be seen as a method of hedging against the risk of stock outs. As the risk of stock-outs increase, the risk premium processors are willing to pay for the hedge, goes up. By looking at the convenience yield as a premium paid to hedge storage, the irrational behavior of holding inventories under backwardation transforms into simple risk minimizing behavior.

In this sense, physical inventories can be said to hold an endowment effect for the processor. In behavioral economics, endowment effects are assumed to influence an individual's willingness to accept. Thus, an increase in a commodity's endowment effect could cause the market to become less liquid, since some inventory holders affected by this endowment, will demand a greater price than the market consensus. This mismatch of buy and sell prices can be a reason to why inventory is carried in periods of negative return to storage.

One of the most important concepts in Kahneman and Tversky's prospect theory is hyperbolic loss aversion. Briefly, the theory suggests that people tend to feel losses greater than gains. Through several studies it has been shown that the disutility from a loss is given a 2-3 times higher weight than the utility from a gain (Kahneman & Riepe, 1998; Kahneman & Tversky, 1979).

By not to selling out stocks at times when the spot price offers an opportunity of excess returns, the processor must somehow consider the potential loss of not holding inventory as greater than the potential gain of selling. This indicates that a possibility for a loss greater than approximately 2/5 of the possible gain achieved by going completely naked in a cash and/or futures positions, should lead to storing also during times with negative returns.

There can also be many other possible reasons to why some market participants choose to store commodities under inverted market conditions. As pointed out by Joseph et.al. (2011), commercial obligations are probably one of the most common reasons.

Additionally, a more active trading strategy also comes at a greater financial cost. For producers and processors, it can also be assumed that the futures market's main roll is first of all to offer long term safety regarding future cash flows, and not short term speculative profits like those offered by a negative NCS.

8 Conclusion

1) Does the theory of storage offer any explanation to movements in the price spread between the spot price and the futures price in the U.S. market for corn, soybeans, wheat, WTI and copper (1990-2012)?

The results presented in this thesis verify that the behavior of the spot-futures spread is very much in accordance with the theory of storage, and the existence of a convenience yield.

By focusing on the yearly term structure of the net cost of storage found in table 5, it is possible to see that this variable is consistent with the expected behavior of a convenience yield, especially in the market for corn, wheat and WTI. For these markets the convenience yield is found to be an accumulating process of time to delivery, verifying the excess value of physical ownership.

The estimated effect of the variables included in model 1 and model 2, also confirms that changes in the net cost of storage is significantly related to variables that are assumed to affect the convenience yield of a storable commodity. The estimated parameter corresponding to the inventory holds the most prominent evidence of a convenience yield. This parameter is found to be significant for all five commodities, signifying a positive non-linear relationship between the net cost of storage and the inventory level. From the inventory elasticities, it is possible to see that the net cost of storage for WTI is very sensitive to fluctuations in the inventory. This is related to the fairly stable supply of WTI, indicating that the market considers changes in the inventory in a relative and not absolute way.

By conducting comparative statistics on model 1 and model 2, the thesis also suggests that seasonal cycles in the supply affect the inventory variable effect on the net cost of storage. By keeping the variables unadjusted for seasonality, the inventory variable's effect on the longest contract spread for corn, wheat and soybeans is statistically insignificant. The longest futures contract include for these commodities is consequently delivered after the next harvest period, indicating that this contract represent a different storage scenario. The results verify that this also affects the pricing of this contract, as it does not depend on the current inventory level.

In conjunction with this, I have included a specific example on how rollover of futures contracts affects the price spread between spot and futures prices. The example in figure 3 shows how large fluctuations in the NCS often are caused by a lack of convergence between the spot price and the futures price. A decreasing covariance between spot and futures prices can be explained by an increasing convenience yield, giving a higher value to present ownership of a commodity. The example of corn prices from 1996, points out how the valuation of agricultural commodities are affected by seasonality in the supply. Furthermore, the graphics in figure 3 demonstrates how futures contracts with different delivery after the harvest offers a different storage scenarios, resulting in different movements in the convenience yield for these contract spreads.

The effect of changes in the relative spot price volatility proved to be consistently negative and statistically significant for several contract spreads. This illustrates how the convenience yield becomes larger in times of increasing insecurity in the spot prices, signifying that the convenience yield also acts as a premium that is paid to hedge physical inventory.

The results from the regression analysis also indicate that the variation in the NCS is affected by a possible risk premium, determined by the net commercial hedging pressure. The data analysis shows that the relationships derived from the theory of storage do not necessary exclude the relationship proposed by the theory of normal backwardation. The two theories actually seem to coexist, as the partial effect of a change in the commercial net hedging pressure is found to be both negative and significant.

To answer the first research question, the theory of storage does indeed hold some explanatory power over the price spread between the spot price and the futures price. Nonetheless, the models fail to explain more than 60% of the variation in the net cost of storage.

As the net cost of storage tends to be a mean reverting process, different auto regressive models have proven to offer a higher degree of explanatory power than achieved through the ANCOVA model applied in this thesis (see e.g. Kremser and Rammerstorfer (2010)). Still, the point here is not to predict exact estimates of the net cost of storage, but rather illuminate how this variable is affected by a market fundamental like the inventory level, spot price volatility and commercial net hedging pressure. In this sense, the results are quite satisfying.

2) Did the increase in speculative positions after 1999 affect the behavior of the convenience yield?

The second research question is answered by testing for changes in the models parameters after 1999. A Chow test and a dummy variable test for structural breaks confirm that the models yield different parameters in each of the two sub-samples.

The most evident result of a structural break is found within the NCS for wheat. In this case, the effect of the inventory variable decreased significantly after 1999. This change is consistent with a change in the overall pricing regime of the market, possibly caused by an increase in the number of speculative positions. The shape of the sub-sample Working curves for wheat, also suggests that increasing speculative activity did affect the NCS, as the Working curve adopts a shape more typical for non-commercial trading (See A.Figure 9 in appendix). The number of months in backwardation also decreased significantly in the period after 1999.

A similar change in the variables is also found in the NCS_{1-2} for corn, indicating that the short term convenience yield for this commodity was estimated differently after 1999. The structural break occurring in the other models for corn was mostly related to changes in the relative spot price volatility, and not the inventory variable. Thus, there are no significant indications of change in the valuation of owning physical corn relative to long term contracts.

The effect of the soybean inventory on the NCS also experienced a significant change after 1999 for all the contract spreads. However, these breaks were not large enough to alter the general shape of the commodity's Working curve. In this regard, low soybean stocks continued to create negativity in the short term NCS. As for the $NCS_{1-5,1-6 \text{ and} 1-7}$, the effect of the inventory variable becomes very small and insignificant after 1999. These findings indicate that the changes in the long term convenience yield did not depend on changes in the inventory variable.

As for WTI, the change in the inventory variable is significant for the long term NCS, but not for the short term. The WTI Working curves indicate that the convenience yield continued to be a decreasing function of the inventory level for the $NCS_{1-2,}$ also after 1999. The parameter measuring the effect of the inventory variable remains significant in both sub-samples, pointing to no conclusive evidence of an alteration in the valuation of the convenience yield for WTI.

These results cannot fully conclude that the valuation of the convenience yield was affected by the increasing number of speculative positions after 1999. Nevertheless, the results clearly predicts a change in the effect of the variables that is consistent with a more speculative pricing approach, giving less weight to fundamental indicators like the storage level.

> *3) How can the convenience yield be related to behavioral and economical reasons to store commodities during times with negative return to storage?*

As emphasized in chapter 7, different market participants have different incentives to store commodities at a negative return. As discussed, these reasons can be fully rational or potentially caused by factors related to human psychology and misinterpretations of the market price.

For those who use commodities as an input in a production process, keeping physical commodities can act as insurance towards insecurity in supply and demand. In the case of negative returns to storage, this return simply becomes a premium paid to minimize the risk associated with changes in supply or demand.

For a producer, storing commodities at a loss cannot be rationalized from a purely profit maximizing stand. On the other hand, behavioral concepts like anchoring, overconfidence, reference prices and loss aversion offer possible explanations to why some agents may wrongfully choose to store commodities at an expected loss.

From the discussion it becomes clear the different market participants have different economical, commercial and behavioral excuses to store inventory during backwardation. Some of them might be perfectly rational, while others are based on misconceptions and wrongful interpretation of the market information.

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Appendix

Summary of time relation between contracts

A.Table 1: Contract spreads Corn, Wheat and Copper by calendar months

Month	NCS $_{1-2}$	NCS $_{1-3}$	NCS $_{1-4}$	NCS$_{1-5}$
Jan	Mar-May	Mar-Jul	Mar-Sep	Mar-Dec
Feb	Mar-May	Mar-Jul	Mar-Sep	Mar-Dec
Mar	Mar-May	Mar-Jul	Mar-Sep	Mar-Dec
Apr	May-Jul	May-Sep	May-Dec	May-Mar
May	May-Jul	May-Sep	May-Dec	May-Mar
Jun	Jul-Sep	Jul-Dec	Jul-Mar	Jul-May
Jul	Jul-Sep	Jul-Dec	Jul-Mar	Jul-May
Aug	Sep-Dec	Sep-Mar	Sep-May	Sep-Jul
Sep	Sep-Dec	Sep-Mar	Sep-May	Sep-Jul
Oct	Dec-Mar	Dec-May	Dec-Jul	Dec-Sep
Nov	Dec-Mar	Dec-May	Dec-Jul	Dec-Sep
Dec	Dec-Mar	Dec-May	Dec-Jul	Dec-Sep

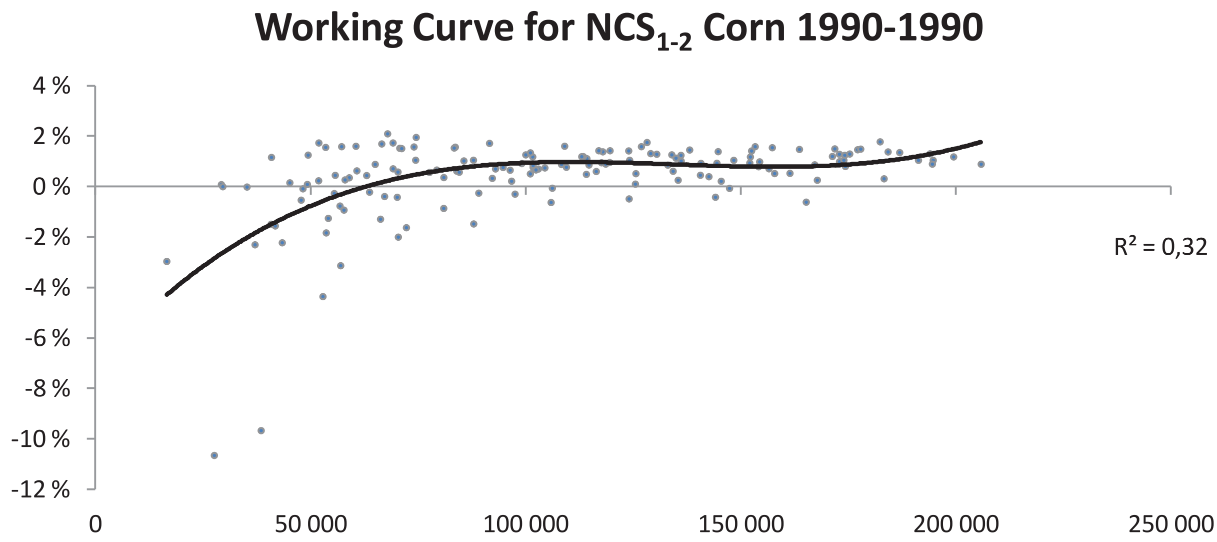
A.Table 2: Contract spreads Soybeans by calendar months

Month	NCS $_{1-2}$	NCS $_{1-3}$	NCS $_{1-4}$	NCS $_{1-5}$	NCS $_{1-6}$	NCS $_{1-7}$
Jan	Jan-Mar	Jan-May	Jan-Jul	Jan-Aug	Jan-Sep	Jan-Nov
Feb	Mar-May	Mar-Jul	Mar-Aug	Mar-Sep	Mar-Nov	Mar-Jan
Mar	Mar-May	Mar-Jul	Mar-Aug	Mar-Sep	Mar-Nov	Mar-Jan
Apr	May-Jul	May-Aug	May-Sep	May-Nov	May-Jan	May-Mar
May	May-Jul	May-Aug	May-Sep	May-Nov	May-Jan	May-Mar
Jun	Jul-Aug	Jul-Sep	Jul-Nov	Jul-Jan	Jul-Mar	Jul-May
Jul	Jul-Aug	Jul-Sep	Jul-Nov	Jul-Jan	Jul-Mar	Jul-May
Aug	Aug-Sep	Aug-Nov	Aug-Jan	Aug-Mar	Aug-May	Aug-Jul
Sep	Sep-Nov	Sep-Jan	Sep-Mar	Sep-May	Sep-Jul	Sep-Aug
Oct	Nov-Jan	Nov-Mar	Nov-May	Nov-Jul	Nov-Aug	Nov-Sep
Nov	Nov-Jan	Nov-Mar	Nov-May	Nov-Jul	Nov-Aug	Nov-Sep
Dec	Jan-Mar	Jan-May	Jan-Jul	Jan-Aug	Jan-Sep	Jan-Nov

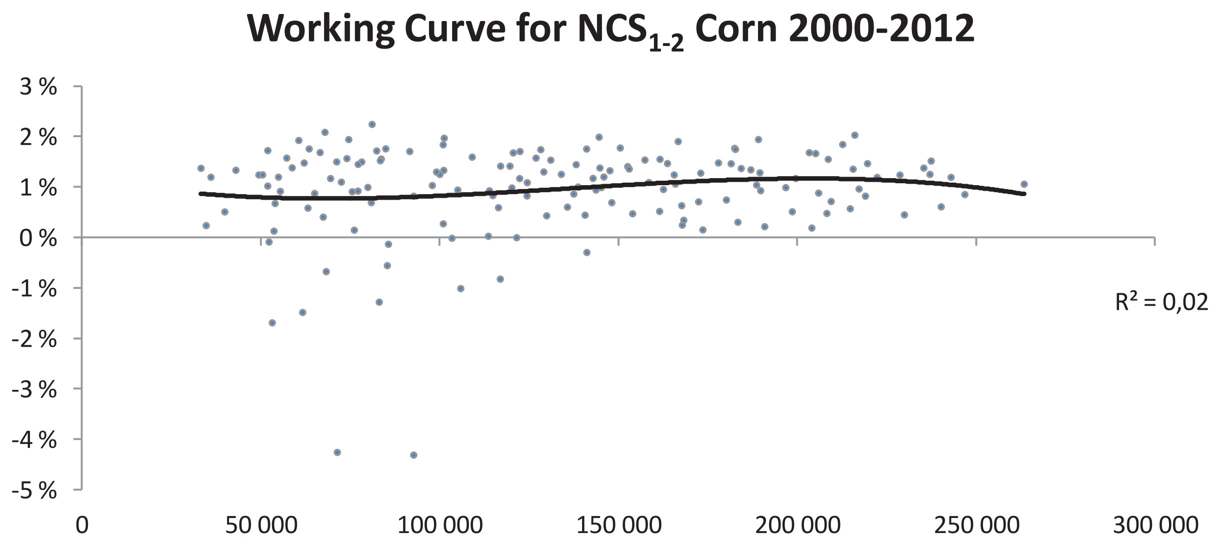
A.Table 3: Contract spreads WTI by calendar months

Month	NCS $_{1-2}$	NCS $_{1-3}$	NCS $_{1-6}$	NCS $_{1-9}$	NCS $_{1-12}$
Jan	Jan-Feb	Jan-Mar	Jan-Jun	Jan-Sep	Jan-Dec
Feb	Feb-Mar	Feb-Apr	Feb-Jul	Feb-Oct	Feb-Jan
Mar	Mar-Apr	Mar-May	Mar-Aug	Mar-Nov	Mar-Feb
Apr	Apr-May	Apr-Jun	Apr-Sep	Apr-Dec	Apr-Mar
May	May-Jun	May-Jul	May-Oct	May-Jan	May-Apr
Jun	Jun-Jul	Jun-Aug	Jun-Nov	Jun-Feb	Jun-May
Jul	Jul-Aug	Jul-Sep	Jul-Dec	Jul-Mar	Jul-Jun
Aug	Aug-Sep	Aug-Oct	Aug-Jan	Aug-Apr	Aug-Jul
Sep	Sep-Oct	Sep-Nov	Sep-Feb	Sep-May	Sep-Aug
Oct	Oct-Nov	Oct-Dec	Oct-Mar	Oct-Jun	Oct-Sep
Nov	Nov-Dec	Nov-Jan	Nov-Apr	Nov-Jul	Nov-Oct
Dec	Dec-Jan	Dec-Feb	Dec-May	Dec-Aug	Dec-Nov

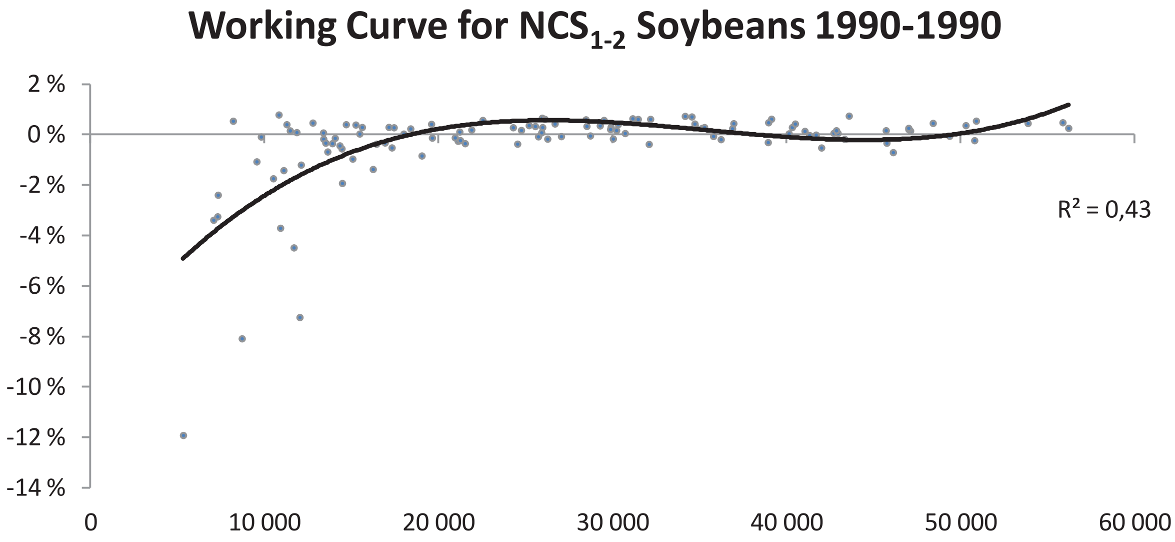
Empirical Working curves from subsamples of 1990-1999 and 2000-2012



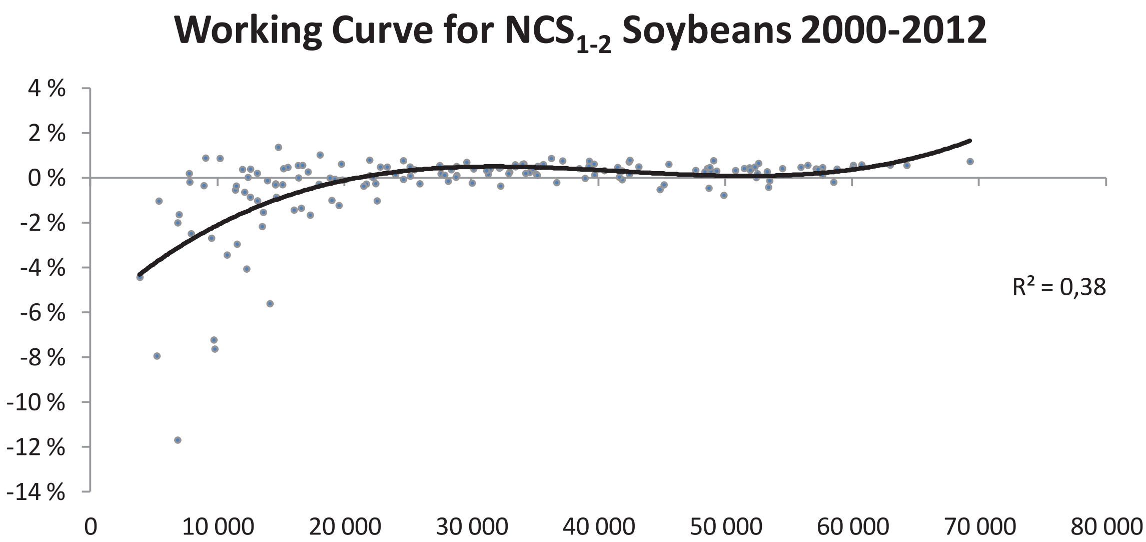
A.Figure 1: Empirical Working curve for Corn based on monthly NCS and storage levels from 1990-1999



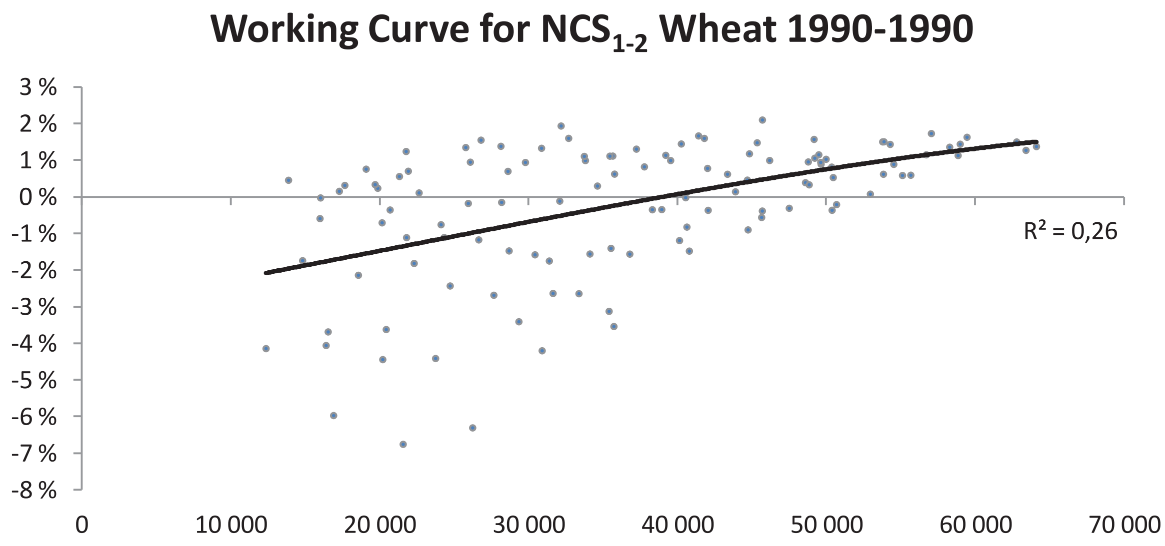
A.Figure 2: Empirical Working curve for Corn based on monthly NCS and storage levels from 2000-2012



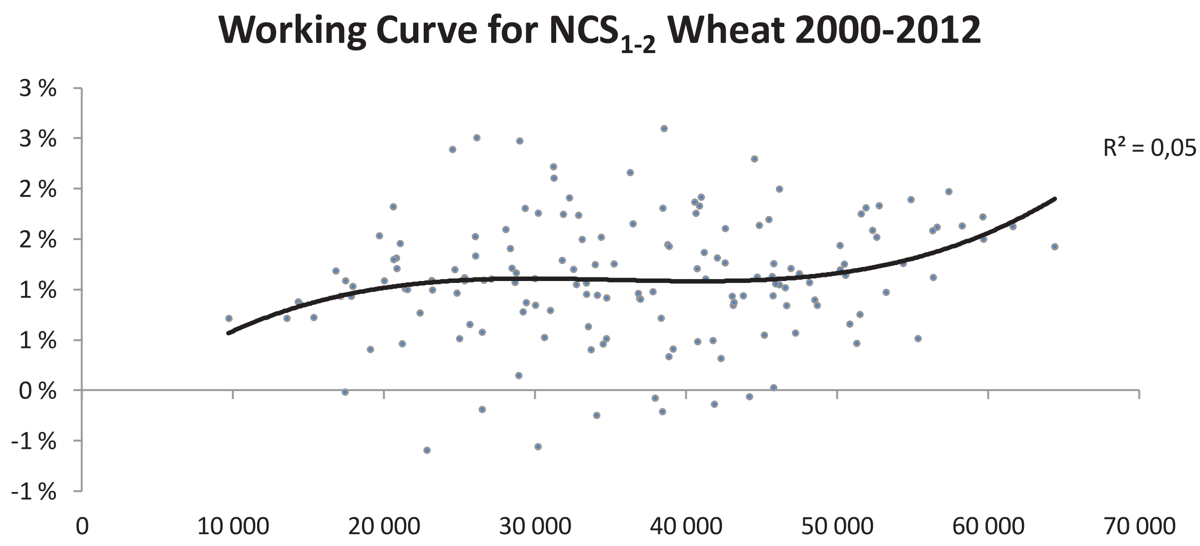
A.Figure 3: Empirical Working curve for Soybeans based on monthly NCS and storage levels from 1990-2012



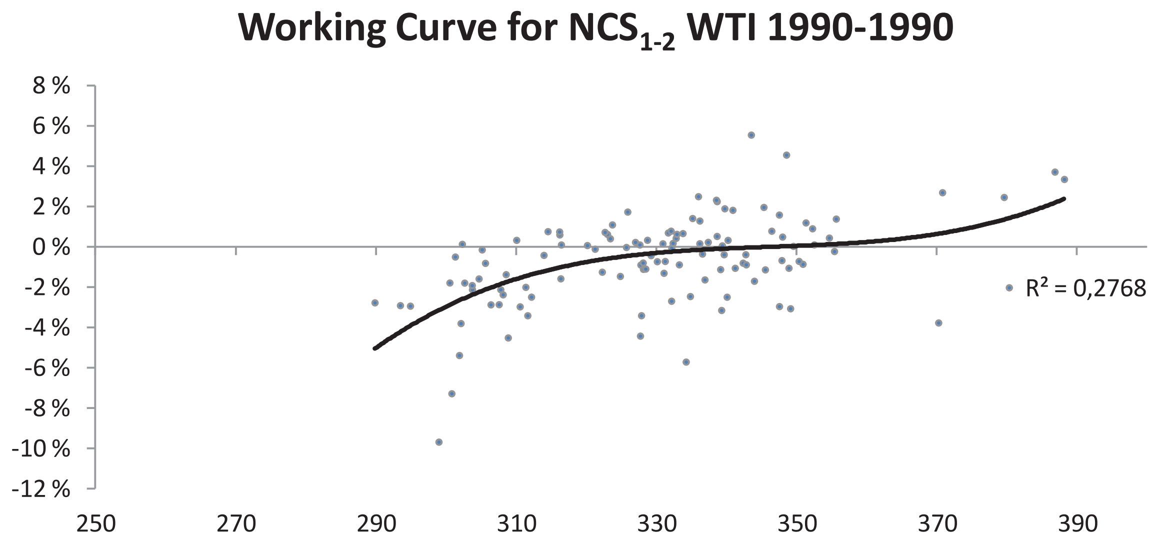
A.Figure 4: Empirical Working curve for Soybeans based on monthly NCS and storage levels from 2000-2012



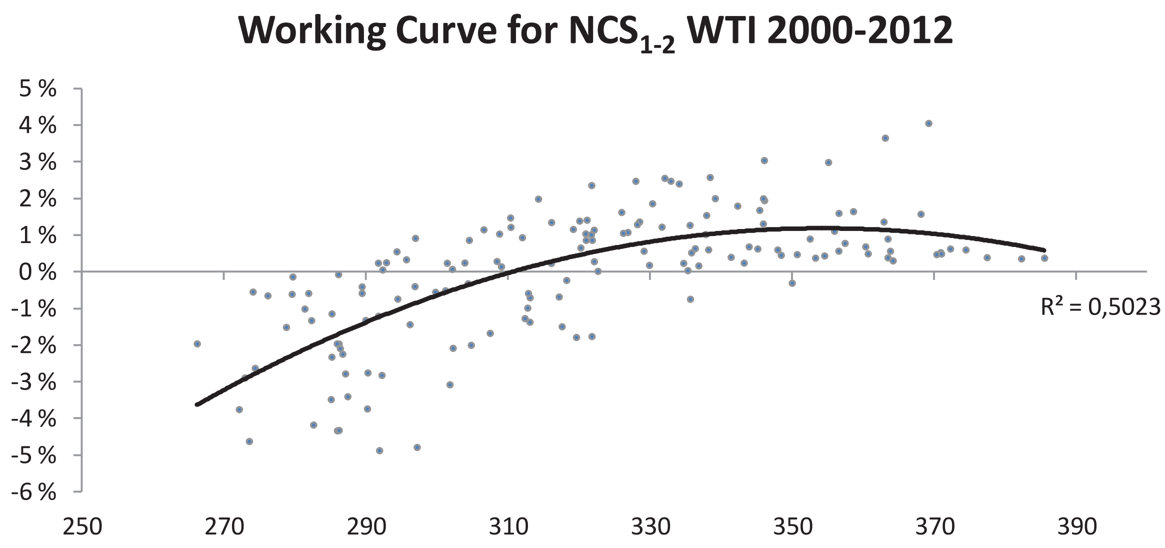
A.Figure 5: Empirical Working curve for Wheat based on monthly NCS and storage levels from 1990-2012



A.Figure 6: Empirical Working curve for Wheat based on monthly NCS and storage levels from 1990-2012



A.Figure 7: Empirical Working curve for WTI based on monthly NCS and storage levels from 1990-1999



A.Figure 8: Empirical Working curve for WTI based on monthly NCS and storage levels from 2000-2012

Regression results from subsamples of 1990-1999 and 2000-2012

A.Table 4: Results from OLS regression of equation 9 and 12 for Corn (1990-1999)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,02*	-1489,57***	-0,002	0,013**	-0,010**	-0,004	-	5,21***	0,42
Model 2	0,06	-2466,96***	-0,0007	-0,038	-0,003	-0,002	3,03***	5,75***	0,58
Contract (1-3)									
Model 1	0,03	-705,50***	-0,002***	-0,008	-0,010***	-0,006	-	10,27***	0,34
Model 2	0,07	-1790,96***	-0,0003	-0,048	-0,003	-0,003	2,29**	5,22***	0,53
Contract (1-4)									
Model 1	0,03*	-200,59**	-0,003***	-0,016	-0,006***	-0,007**	-	12,09***	0,41
Model 2	0,06*	-983,44***	-0,001**	-0,035	-0,002	-0,006**	2,86***	4,72***	0,52
Contract (1-5)									
Model 1	0,02*	-188,71	-0,002***	-0,014	-0,004***	-0,007	-	10,80***	0,42
Model 2	0,05	-808,67***	-0,001	-0,002	-0,002	-0,006**	3,33***	5,84***	0,52

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 5: Results from OLS regression of equation 9 and 12 for Corn (2000-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,03***	-415,00**	-0,006	0,0004	-0,004	-0,006***		2,62**	0,16
Model 2	0,04	-1990,36***	-0,005	0,001	-0,004	-0,004***	4,08***	5,42***	0,46
Contract (1-3)									
Model 1	0,02***	-300,08**	-0,009***	0,0004	-0,004**	-0,008***		3,92***	0,30
Model 2	0,04***	-1533,86***	-0,008***	0,001	-0,002	-0,005***	4,02***	7,32***	0,56
Contract (1-4)									
Model 1	0,02***	-134,73	-0,006***	-0,001	-0,003***	-0,008***		10,68**	0,39
Model 2	0,03***	-1236,26***	-0,006***	-0,0003	-0,001	-0,006***	5,28***	13,52***	0,63
Contract (1-5)									
Model 1	0,02***	-75,95	-0,004***	-0,002	-0,001	-0,009***		8,07***	0,40
Model 2	0,02***	-1241,66***	-0,003***	-0,0003	0,0003	-0,006***	5,00***	12,82***	0,65

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 6: Results from OLS regression of equation 9 and 12 for Soybeans (1990-1999)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t{}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t{}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,01***	-317,33***	-0,001***	0,006	-0,005***	0,009***		47,93***	0,52
Model 2	0,08***	-1144,03***	-0,001***	0,014	0,003	-0,001	6,19***	32,22***	0,83
Contract (1-3)									
Model 1	0,01**	-262,70**	-0,0003	0,019	-0,004***	0,006**		9,31***	0,39
Model 2	0,08***	-825,03***	-0,0001	0,015	-0,001	-0,002	7,52***	9,97***	0,67
Contract (1-4)									
Model 1	0,005***	-146,45**	-0,0001	0,015	-0,005***	0,004		4,56***	0,29
Model 2	0,07***	-590,76***	-0,0001	-0,0004	-0,001	-0,004	4,78***	5,04***	0,63
Contract (1-5)									
Model 1	0,003**	-56,72	-0,0007	0,004	-0,005**	0,002		2,71**	0,22
Model 2	0,06***	-438,56***	-0,0006	-0,007	-0,001	-0,005	4,97***	4,42***	0,61
Contract (1-6)									
Model 1	0,001	-14,98	-0,0007	-0,006	-0,004**	0,0003		2,05	0,23
Model 2	0,05***	-299,49***	-0,0006	-0,008	-0,001	-0,005***	5,79***	5,47***	0,61
Contract (1-7)									
Model 1	0,001**	-19,54	-0,0004	-0,006	-0,003	-0,0002		2,13	0,18
Model 2	0,04***	-296,76***	-0,0003**	-0,010**	-0,001	-0,005***	6,13***	5,31***	0,59

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 7: Results from OLS regression of equation 9 and 12 for Soybeans (2000-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t{}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t{}^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,022***	-226,35***	-0,012**	0,005	-0,004**	0,002		7,74***	0,45
Model 2	0,007***	-476,88***	-0,010***	-0,001	-0,002	0,001	5,01***	7,38***	0,66
Contract (1-3)									
Model 1	0,013***	-142,36***	-0,005*	0,006	-0,006**	-0,0006		6,35***	0,33
Model 2	-0,007	-306,26***	-0,004**	-0,002	-0,005**	-0,0006	2,65***	4,62***	0,58
Contract (1-4)									
Model 1	0,008***	-46,43	-0,003***	-0,002	-0,007***	-0,002		10,45***	0,31
Model 2	-0,007	-183,73**	-0,002***	-0,003	-0,006**	-0,002	1,64	9,95***	0,54
Contract (1-5)									
Model 1	0,006***	3,24	-0,003***	-0,004**	-0,007***	-0,002		7,20***	0,36
Model 2	-0,004***	-91,61	-0,002***	-0,004**	-0,006***	-0,003	1,70	5,90***	0,52
Contract (1-6)									
Model 1	0,004	19,05	-0,002***	-0,005**	-0,006***	-0,003**		7,89***	0,36
Model 2	-0,006***	-55,15	-0,001***	-0,004**	-0,006***	-0,003**	1,38	6,28***	0,44
Contract (1-7)									
Model 1	0,004	16,56	-0,001***	-0,004**	-0,006***	-0,004***		11,07***	0,37
Model 2	-0,003	-49,65	-0,001***	-0,004**	-0,004***	-0,004**	1,06	6,63***	0,43

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 8: Results from OLS regression of equation 9 and 12 for Wheat (1990-1999)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,009	-484,02***	0,0002	0,018**	-0,009**	0,009		8,27***	0,33
Model 2	0,16***	-1283,95***	-0,0001	-0,027	-0,002	0,014	10,45***	10,67***	0,62
Contract (1-3)									
Model 1	0,005	-267,39***	-0,0004	0,017***	-0,004**	0,004		12,23***	0,40
Model 2	0,071***	-609,83***	-0,0003**	-0,014*	-0,002	0,006	8,51***	10,87***	0,63
Contract (1-4)									
Model 1	0,003**	-159,46**	-0,0002	0,018**	-0,007**	0,003		4,96***	0,25
Model 2	0,088**	-639,55***	-0,0001**	-0,023**	-0,004	0,005	6,19***	10,00***	0,64
Contract (1-5)									
Model 1	0,002	46,84	-0,0008**	-0,015	-0,009***	0,0003		4,23***	0,26
Model 2	-0,072	-554,63***	-0,0005	-0,023**	-0,004	0,002	4,34***	8,44***	0,61

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 9: Results from OLS regression of equation 9 and 12 for Wheat(2000-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^2 + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,027***	-78,06**	-0,011***	0,0002	-0,004***	-0,0004		6,94***	0,21
Model 2	0,026***	-338,99***	-0,008***	-0,0009	-0,004***	0,0001	5,27***	8,76***	0,52
Contract (1-3)									
Model 1	0,001***	-65,23***	-0,002***	-0,0002	-0,001	-0,0008		7,17***	0,21
Model 2	0,010***	-175,98***	-0,002***	-0,0006	-0,001**	0,0001	5,04***	8,05***	0,49
Contract (1-4)									
Model 1	0,012***	-87,91***	-0,002***	0,0005	-0,0004	-0,0019		13,53***	0,26
Model 2	0,013***	-316,61***	-0,002***	-0,0008	-0,001	-0,0014	4,76***	14,46***	0,49
Contract (1-5)									
Model 1	0,012***	-49,71	-0,003***	0,0004	-0,0008	-0,0017		13,03***	0,40
Model 2	0,015***	-342,77***	-0,003***	-0,0010	-0,002	-0,0017	6,13***	17,55***	0,61

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 10: Results from OLS regression of equation 9 and 12 for WTI (1990-1999)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,16***	-45,02***	-0,018**	-0,003	-0,006	-0,012**		9,30***	0,45
Model 2	-0,14	-93,44***	-0,016**	-0,004	-0,007***	-0,010**	0,68	10,59***	0,68
Contract (1-3)									
Model 1	0,12***	-37,12***	-0,006***	-0,009	-0,006	-0,011**		15,09***	0,43
Model 2	-0,14	-81,12***	-0,004***	-0,041	-0,007**	-0,008**	0,61	16,71***	0,66
Contract (1-6)									
Model 1	0,08***	-26,18***	-0,001***	-0,012	-0,005*	-0,008**		19,12***	0,36
Model 2	-0,12	-59,96***	-0,001	-0,036	-0,005**	-0,007**	0,71	19,47***	0,59
Contract (1-9)									
Model 1	0,06**	-19,43**	-0,0006***	-0,013	-0,003	-0,006**		24,23***	0,32
Model 2	-0,10	-47,04***	-0,0003***	-0,031	-0,004	-0,005**	0,90	19,01***	0,56
Contract (1-12)									
Model 1	0,06**	-15,17**	-0,0005**	-0,012	-0,003	-0,005**		22,08***	0,32
Model 2	-0,09	-38,34***	-0,0003	-0,027**	-0,003**	-0,004**	1,00	11,51***	0,54

Significant parameters are marked with *, ** and *** for 10%, 5% and 1% significance level, respectively. HAC standard errors are used.

A.Table 11: Results from OLS regression of equation 9 and 12 for WTI (2000-2012)

Model 1: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \varepsilon_{1,n,t}$

Model 2: $NSC_{1-n,t} = \alpha + \beta_1 I_t^{-1} + \beta_2 V_t^{\,2} + \beta_3 \Delta CC_{1,n,t} + \beta_4 D_{Invent,t} + \beta_5 D_{NHP,t} + \beta_6 t + \sum_{m=1}^{12-1} \delta_t D_{m,t} + \varepsilon_{1,n,t}$

	α	β_1	β_2	β_3	β_4	β_5	$D_m(F)$	F-value	R^2
Contract (1-2)									
Model 1	0,15***	-46,07***	-0,005	0,0012	0,002	-0,003		7,32***	0,35
Model 2	0,16***	-50,99***	-0,004	-0,0003	0,001	-0,002	0,68	3,29***	0,41
Contract (1-3)									
Model 1	0,14***	-41,85***	-0,006	-0,0003	0,002	-0,004		10,08***	0,44
Model 2	0,15***	-45,47***	-0,005	-0,0020	0,001	-0,003	0,54	5,47***	0,49
Contract (1-6)									
Model 1	0,11***	-32,67***	-0,004***	-0,002	0,001	-0,005***		25,32***	0,59
Model 2	0,10***	-32,69***	-0,003***	-0,003	0,001	-0,005***	0,46	10,65***	0,62
Contract (1-9)									
Model 1	0,09***	-27,88***	-0,002***	-0,003	0,001	-0,004***		33,30***	0,64
Model 2	0,08***	-25,91***	-0,001***	-0,003	0,001	-0,004***	0,54	9,61***	0,68
Contract (1-12)									
Model 1	0,08***	-24,95***	-0,001***	-0,003	0,001	-0,003***		17,63***	0,63
Model 2	0,06***	-21,46***	-0,001***	-0,003	0,001	-0,003**	0,63	8,14***	0,69

Significant parameters are marked with ** and *** for 5% and 1% significance level, respectively. HAC standard errors are used.

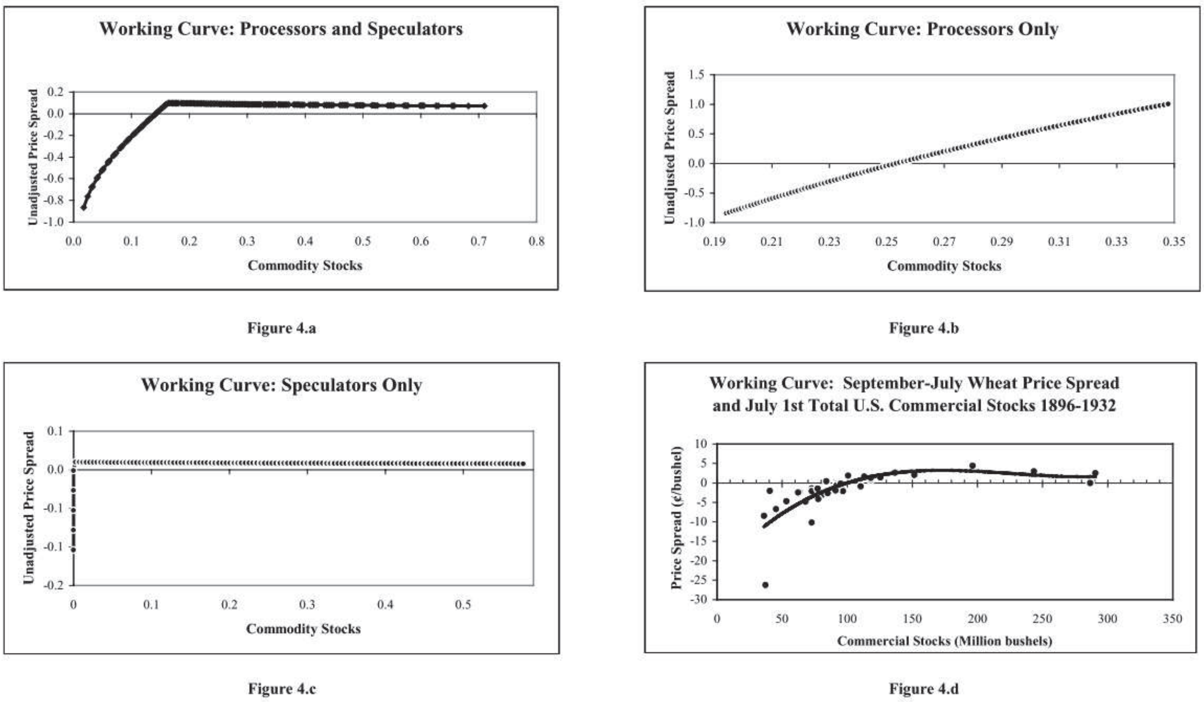
Chow test

A.Table 12: Results from Chow test, F-statistics reported

Commodity $_{1-n}$	**Model 1 ($F_{crit, 5\%}$ = 2,37)**	**Model 2 ($F_{crit, 5\%}$ = 1,67)**
Corn $_{1-2}$	6,50	2,43
Corn $_{1-3}$	1,93*	3,70
Corn $_{1-4}$	8,17	3,56
Corn $_{1-5}$	7,83	3,57
Soybeans $_{1-2}$	2,54	5,59
Soybeans $_{1-3}$	2,78	3,52
Soybeans $_{1-4}$	3,26	3,94
Soybeans $_{1-5}$	3,08	3,93
Soybeans $_{1-6}$	2,27*	3,35
Soybeans $_{1-7}$	3,55	3,38
Wheat $_{1-2}$	21,34	6,86
Wheat $_{1-3}$	24,68	6,20
Wheat $_{1-4}$	14,71	4,67
Wheat $_{1-5}$	11,24	3,55
WTI $_{1-2}$	6,64	4,45
WTI $_{1-3}$	6,32	4,70
WTI $_{1-6}$	8,45	5,71
WTI $_{1-9}$	6,98	5,72
WTI $_{1-12}$	4,85	5,48

*the null hypothesis "no structural break" cannot be rejected at a 5% significance level

Working curves as predicted by César L. Revoredo (2000)



A.Figure 9: Working curves as predicted by César L. Revoredo (2000)