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ABSTRACT

Commodity futures risk premiums vary across commodities and over time depending on the level of physical inventories, as predicted by the Theory of Storage. Using a comprehensive dataset on 31 commodity futures and physical inventories between 1969 and 2006, we show that the convenience yield is a decreasing, non-linear relationship of inventories. Price measures, such as the futures basis, prior futures returns, and spot returns reflect the state of inventories and are informative about commodity futures risk premiums. The excess returns to Spot and Futures Momentum and Backwardation strategies stem in part from the selection of commodities when inventories are low. Positions of futures markets participants are correlated with prices and inventory signals, but we reject the Keynesian "hedging pressure" hypothesis that these positions are an important determinant of risk premiums.

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1. Introduction

In this paper we analyze the fundamentals of commodity futures risk premiums. We show that time-series variation and cross-sectional variation in commodity futures risk premiums are determined by the level of inventories of the commodity in the economy. The starting point of our analysis is the traditional Theory of Storage. Originally proposed by Kaldor (1939), the theory provides a link between the term structure of futures prices and the level of inventories of commodities. This link, also known as “cost of carry arbitrage,” predicts that in order to induce storage, futures prices and expected spot prices of commodities have to rise sufficiently over time to compensate inventory holders for the costs associated with storage.

In addition to market expectations of future spot prices, futures prices potentially embed a risk premium that is a compensation for insurance against future spot price risk. Whether futures prices also embed risk premiums has been more controversial in the literature. In part, this controversy stems from the difficulty in detecting risk premiums in volatile markets using small samples, and the lack of correlation of commodity futures returns with conventional measures of systematic risk suggested in the asset pricing literature.

To formalize the link between futures prices and risk premiums, we start by presenting a simple theoretical extension of the theory of inventory behavior developed by Deaton and Laroque (DL 1992), and Routledge, Seppi and Spatt (RSS, 2000). Their models predict a link between the level of inventories and future spot price volatility. Inventories act as buffer stocks which can be used to absorb shocks to demand and supply, thus dampening the impact on spot prices. DL show that at low inventory levels, the risk of a “stock-out” (exhaustion of inventories) increases and expected future spot price volatility rises. In an extension of the DL model which includes a futures market, RSS show how the shape of the futures curve reflects the state of inventories and signals expectations about future spot price volatility. DL (1992) and RSS (2000) have explained the existence of a convenience yield as arising from the probability of a stock-out of inventories. Because they study storage in a risk-neutral world, risk premiums are zero by construction, and futures prices simply reflect expectations about future spot prices.

To allow for a link between inventories and futures risk premiums, we extend the DL model to include risk-averse agents and a hedging motive on behalf of producers. Our model predicts a link between the state of inventories, the shape of the futures curve, and expected futures risk premiums. Given that futures contracts provide insurance against price volatility, the level of inventories is negatively related to the required risk premium of commodity futures. The main contribution of our paper is to provide an empirical test of these predictions.

Despite the long history of the traditional Theory of Storage, surprisingly few researchers have attempted to directly test the theory using inventory data.[1] Often cited reasons include problems related to the availability and the poor quality of inventory data, and issues regarding the appropriate definition of relevant inventories. Most tests of the Theory of Storage have focused instead on testing predictions about the (relative) volatility of spot and futures prices.

The first contribution of this paper is to present monthly measures of inventories for a large cross-section of 31 commodities between 1969 and 2006, and show that these measures of inventories are reflected in the shape of the futures curve as predicted by the Theory of Storage. As with much of the previous literature our initial focus is on the *basis*, the difference between the *current* spot commodity price and the current (nearest to maturity) futures price (expressed as a percentage of the spot price).[2] We link the basis to the level of inventories, and empirically document the nonlinear relationship predicted by the existence of the non-negativity constraint on inventories. In particular, low inventory levels for a commodity are associated with an inverted ("backwardated") term structure of futures prices, while high levels of inventories are associated with an upward sloping futures curve ("contango"). In addition, we show that the relationship between inventories and the shape of the futures curve is non-linear: the slope of the futures curve becomes steeper as inventories decline.

The second contribution of the paper is to document an empirical link between inventories and risk premiums. We present two sets of tests to examine whether inventory levels are negatively associated with risk premiums on commodity futures. The first set of tests uses inventories directly as explanatory variables for risk premiums. In addition to simple regression based evidence, we show that sorting commodity futures into portfolios based on inventory measures is correlated with future average returns. While a direct test of the theory, the interpretation of these findings is complicated by an unknown timing lag in the information release of inventories data, and subsequent data revisions. The second set of tests uses price-based signals to proxy for inventories. We first show that the futures basis, prior futures returns, and prior spot price changes are correlated with current inventory levels. Next, we show that these price-based measures of inventories are informative about the expected returns of portfolios sorted on these measures. Inspection of the inventory characteristics of these sorted portfolios confirms that the risk premiums carry a common component, earned in part by investing in

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[1] Exceptions include Dincerler, Khokher and Titman (2003), and Dincerler, Khokher and Simin (2004). The former paper examines the effect of Storage on Natural Gas futures returns between 1994 and 2001; the latter paper examines the role of inventories and hedging pressure for risk premiums in futures of Gold, Copper, Crude Oil, and Natural Gas between 1995 and 2004.

[2] The "spot price" is usually taken to mean the nearest future contract (i.e., the contract that is closest to maturity) and the "futures price" means the next nearest futures contract.

commodities in low inventory states. The returns earned on “momentum” and “backwardation” strategies can therefore be interpreted as compensation earned for bearing risk during times when inventories are low.

Finally, we characterize the behavior of market participants in futures markets in response to changes in inventories. This is of interest because much of the literature on commodity futures has assigned an important role to the behavior of market participants in setting risk premiums. For example, in the Theory of Normal Backwardation, Keynes (1930) conjectured that the long side of a commodity futures contract would receive a risk premium due to hedging demand by producers. And in empirical implementations of the Theory of Normal Backwardation, researchers have linked “hedging pressure” to variation in futures risk premiums (e.g., Carter et al (1983), Bessembinder (1992), De Roon et al (2000)). Using data obtained from the Report of Traders released by the Commodity Futures Trading Commission, we show that positions of traders are contemporaneously correlated with inventories and futures prices. However, we find no evidence that these positions are correlated with ex-ante risk premiums of commodity futures. We therefore reject the hedging pressure hypothesis as an alternative explanation for the variation of risk premiums documented in our empirical work.

Our research builds on two strands of literature. The first starts with the traditional Theory of Storage developed by Kaldor (1939), Working (1949), and Brennan (1958), which explained the futures prices in terms of the cost of storage, interest rates, and a convenience yield. The convenience yield was the answer to explain why inventory holders would hold inventories during periods of expected decline of spot prices. Tests of the Theory of Storage include Fama and French (1988) and Ng and Pirrong (1994), among others. Both papers use the interest-adjusted basis as a proxy for inventories and examine the relation between the futures basis and price volatility. Fama and French (1988) analyze daily futures prices of metals over the period 1972 to 1983. Without inventory data, they use two proxies for determining when inventories are low. One proxy is the sign of the interest-adjusted basis. The second proxy is the phase of the business cycle. Fama and French (1988) argue that inventories are relatively low during recessions. With these proxies for inventory levels, they test their hypothesis that futures prices are less variable than spot prices when inventory is low, an implication of the Theory of Storage, according to French (1987). Ng and Pirrong (1994) study four industrial metals. Like Fama and French (1988) they use the adjusted basis as a summary of supply and demand conditions and do not use inventory data. They examine the marginal impact of the basis (the “spread”) on variances, correlations, and elasticities of spot and futures. Their evidence is consistent with a concave, increasing relation between the adjusted spreads and inventories for spot and future return volatilities. Our contribution to this literature is that we directly examine the relationship between the basis and inventories using a large cross-section of commodities. In addition, our sample covers a longer span of time than previous research.

The second strand of literature primarily focuses on variation of risk premiums. Fama and French (1987) study 21 commodity futures using monthly data, over various periods, all ending in July 1984 and starting as early as March 1966. They examine both the variation in the futures basis and the information content in the basis about futures risk premiums. They find evidence that the basis varies with interest rates and seasonals (a proxy for convenience yields, since inventories are higher just after the harvest for agricultural commodities). They also decompose changes in the basis into the change in the expected spot price and the risk premium and conclude that most of the information in the basis concerns expected future spot price movements. Nash (2001), Erb and Harvey (2006), and Gorton and Rouwenhorst (2006) provide recent evidence of a relationship between the futures basis and futures risk premiums. Momentum in commodity futures has been documented by Pirrong (2005), Erb and Harvey (2006), Miffre and Rallis (2007), and Shen, Szakmary, and Sharma (2007). Chang (1985), Bessembinder (1992) and De Roon, Nijman and Veld (2000), Dincerler, Khokher and Titman (2003) and Dincerler, Khokher and Simin (2004) provide empirical evidence that traders' positions are correlated with expected futures returns. Our contribution relative to these papers is to explain the relation between the returns and commodity characteristics as arising from fundamental variation in inventories as predicted by the Theory of Storage. And we show that expected futures returns are driven by inventories, instead of positions of traders.

In addition to these papers, there is a large literature about unconditional risk premiums in commodity futures markets. Attempts to empirically measure the risk premium on individual commodity futures have yielded mixed results (see, for example, Bessembinder (1992), Kolb (1992), and Erb and Harvey (2006)). Most of these studies use small samples in both the time series and cross sectional dimensions. Looking at portfolios of commodity futures returns has produced different results. Bodie and Rosansky (1980), and Gorton and Rouwenhorst (2005, 2006) provide empirical evidence that, consistent with Keynes' and Hicks' prediction, long investors in commodity futures have historically earned a positive risk premium. The issue of reconciling commodity risk premiums with received asset pricing theory has generally been met with limited success (see, for example, Dusak (1973), Jagannathan (1985)). The current paper sheds little light on this debate, other than to suggest that one avenue to look for a unified explanation of risk premiums is to consider systematic components of risk that are correlated with variation of inventories.

The remainder of the paper is organized as follows. In Section 2 we examine the relationship between inventories and futures prices in more detail. We summarize the model in this section. The model itself is formalized in Appendix A. Section 3 presents our data and some stylized facts. Section 4 presents the empirical evidence on the link between futures prices and inventories, and provides evidence that the state of inventories is correlated with expected commodity futures risk premiums. In Section 5 we analyze the returns to price-based commodity selection strategies, linking these price-based signals to time-series and cross-sectional variation in commodity risk premiums. In Section 6 we characterize the behavior of futures markets participants depending on the state of inventories. The final section summarizes our results and suggests some possible avenues for future research.

2. The Theory of Storage and Commodity Futures

In this section we briefly review some of the existing theories and outline our theoretical model and its testable hypotheses. For brevity, our theoretical model is contained in Appendix A.

An upward sloping futures curve is consistent with an expected future spot price that rewards inventory holders for the cost of carrying inventories, including marginal warehousing costs, insurance, and the interest foregone on the capital invested in the inventories. This link between the futures price and the expected future spot price is known as "cost-of-carry" arbitrage. The cost-of-carry argument has difficulty explaining downward sloping futures curves. That is, researchers recognized early on that this argument cannot rationally explain why inventory is held when there is a predictable *decline* in spot prices, when futures prices fall below spot prices – i.e., agricultural products are held over the harvest period when prices predictably fall. To reconcile spot prices at levels above futures prices Kaldor (1939) postulated the existence of a "convenience yield" that holders of physical commodities earn but which does not accrue to holders of futures. This became known as the Theory of Storage.

This Theory of Storage (see, Kaldor (1939), Working (1949), and Brennan (1958)) can be stated in terms of the *basis*, the difference between the contemporaneous spot price in period t, S_t, and the futures price (as of date t) for delivery at date T, $F_{t,T}$ It views the (negative of) the basis as consisting of the cost-of-carry: interest foregone to borrow to buy the commodity, $S_t r_t$,(where r_t is the interest charge on a dollar from t to T), plus the marginal storage costs w_t, minus a "convenience yield," c_t:

$$F_{t,T} - S_t = S_t r_t + w_t - c_t \,. \qquad (1)$$

Equation (1) is often rationalized as following from the absence of arbitrage. Because the convenience yield is unobservable, an alternative view of equation (1) is merely that of a definition of the convenience yield. Economic content for equation (1) is provided by the assertion that the convenience yield, which is the basis adjusted for interest charges and storage costs, falls at a decreasing rate as aggregate inventory rises.

The Theory of Storage derives a relationship between contemporaneous spot and futures prices. Another view of commodity futures is the Theory of Normal Backwardation, which compares futures prices to expected future spot prices. As pointed out by Fama and French (1988), these views are not mutually exclusive. The Theory of Normal Backwardation views futures markets as a risk transfer mechanism whereby long (risk-averse) investors earn a risk premium for bearing future spot risk that commodity producers want to hedge. This theory builds on the view that the basis consists of two components: a risk premium, $\pi_{t,T}$, and the expected appreciation or depreciation of the future spot price:

$$F_{t,T} - S_t = \left[\mathrm{E}_t(S_T) - S_t\right] - \pi_{t,T} \,, \qquad (2)$$

where $\pi_{t,T} \equiv E_t(S_T) - F_{t,T}$. Equation (2) merely defines the risk premium. According to Keynes $\pi_{t,T} > 0$, which implies that the futures price is set at a discount (i.e., is “backwardated”) to the expected future spot price at date T, the date the futures contract expires. Keynes and Hicks (1939) view the risk premium as the outcome of the supply and demand for long and short positions in the futures markets (“hedging pressure”). If hedging demand exceeds the supply of long investors, the risk premium will be positive. The content of the Theory of Normal Backwardation therefore comes from the assertion that hedgers are on net short and offer a risk premium to long investors, who are risk averse.

Since the Theory of Storage and the Theory of Normal Backwardation were first articulated, a large theoretical literature has developed.[3] Our starting point is the modern version of the Theory of Storage due to Deaton and Laroque (1992, henceforth DL).[4] Their goal is to explain the behavior of observed spot commodity prices, which display high volatility, high positive skewness, and significant kurtosis. Commodity prices show infrequent upward spikes,

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[3] The literature on commodity futures is vast, and we make no attempt at a comprehensive survey. Reviews of the literature are provided by Carter (1999), Kamara (1982), and Gray and Rutledge (1971), among others. Telser (2000) provides an overview of the early literature.

[4] See also Williams and Wright (1991).

but no downward spikes. In their model commodity prices, in the absence of any inventories, would be i.i.d. because "harvests" of commodities are i.i.d. These price dynamics are changed fundamentally when inventories are present. Inventories cannot be negative (goods cannot be transferred from the future to the past), so there is a non-negativity constraint on inventories, which "introduces an essential non-linearity which carries through into non-linearity of the predicted commodity price series" (DL, p. 1).

DL do not model futures markets. RSS introduce a futures market into the DL model and show how the "convenience yield" arises endogenously as a function of the inventory level and the shock ("harvests") affecting supply and demand of the commodity. The convenience yield – the benefit accruing to the physical owners of a commodity – arises from the non-negativity constraint on inventories, which creates an option for the inventory holder of selling commodities in the spot market when inventories are low.

In the DL and RSS models agents are risk-neutral. Hence, the commodity futures risk premium, which is central to the Theory of Normal Backwardation of Keynes and Hicks, is zero by assumption. In our model of commodity futures presented in Appendix A, *both* the convenience yield *and* the risk premium emerge endogenously as functions of inventory. In this sense, equations (1) and (2) are both consistent with our equilibrium model. To link the equilibrium spot prices emanating from inter-temporal inventory decisions to commodity futures, we extend the DL model by adding futures markets and risk-averse investors to their model. We also assume that inventory holders face a bankruptcy cost, which provides them with a hedging motive. The existence of the futures market provides the inventory holders with an opportunity to hedge bankruptcy costs. They can use the futures market to transfer future spot price risk to risk averse investors, at a price. The model determines the risk premium paid by the inventory holders to the risk-averse investors, as a function of the extent of the size of the expected bankruptcy costs, the degree of risk aversion of the investors, and the level of inventories. The level of inventories matters for the risk premium because, as in DL, future spot price variance is negatively related to the level of inventories. That is, when inventories are low, the variance of the future spot price is higher due to an increased likelihood of a stock-out, resulting in the risk-averse investors demanding a higher risk premium. The actual amount of hedging may either increase or decrease, depending on the relative sensitivities of the inventory holders and the investors to risk. We can summarize the relevant comparative statistics of the model, as follows.

An inverse and nonlinear basis-inventory relation: Positive demand shocks and negative supply shocks lead to a drop in inventories, and result in an increase in spot prices, signalling the scarcity of the commodity in the spot market. Futures prices will also increase, but not by as much as spot prices. First, futures prices reflect expectations about future spot prices, and embed expectations that inventories will be restored over time and spot prices will return to "normal" levels. Second, the risk premium may increase. Both effects act to widen the difference between spot and futures prices. This inverse relation between the basis and inventory should become more pronounced as the inventory level is near stock-out if the demand for the commodity remains positive for very high prices, which is the case during occasional price spikes. We will be looking for evidence of this nonlinearity. This can be viewed as a test of the DL model of storage dynamics.

An inverse risk premium-inventory relation: When inventories are low and spot prices high, the buffer function of inventories to absorb shocks is diminished. In these circumstances, the risk of a stock-out increases which raises the conditional variance (volatility) of the future spot price. Because commodity futures are used to insure price risk, inventory theory predicts an increase in the risk premium.

Momentum in commodity futures excess returns: Although not formally modelled in our two-period model of Appendix A, inventories can only be restored through new production, a process which can take a considerable amount of time depending on the commodity. Therefore, deviations of inventories from normal levels are expected to be persistent, as are the probability of stock-outs and associated changes in the conditional volatility of spot prices. Because past unexpected increases in spot and futures prices are signals of past shocks to inventories, they are expected to be correlated with expected futures risk premiums. This will induce a form of "momentum" in futures excess returns: the initial unexpected spot price spike due to a negative shock to inventories will be followed by a temporary period of high expected futures returns for that commodity.

We now turn to testing these predictions.

3. Data and Summary Statistics

3.1 Commodity Futures Prices

Monthly data on futures prices of individual commodities were obtained from the Commodities Research Bureau (CRB) and the London Metals Exchange (LME). The details of these data are described in Gorton and Rouwenhorst (2006), who studied all 36 commodities futures that were traded at the four North American exchanges (NYMEX, NYBOT, CBOT, and CME) and the

LME in 2004. For the present study, we drop electricity (because no inventory exists by its very nature), and gold and silver (because these are essentially financial futures). This leaves us with 33 commodities. We constructed rolling commodity futures excess returns by selecting at the end of each month the nearest to maturity contract that would not expire during the next month. That is, the excess return from the end of month t to the next is calculated as:

$$\frac{F_{t+1,T} - F_{t,T}}{F_{t,T}}$$

where $F_{t,T}$ is the futures price at the end of month t on the nearest contract whose expiration date T is after the end of month t+1, and $F_{t+1,T}$ is the price of the same contract at the end of month t+1.

Table 1 contains simple summary statistics for the 33 commodities for periods ending in December 2006. In addition to the 33 commodity futures, the first row of the table (labeled "index") shows the statistics for an equally-weighed, monthly rebalanced, index of the commodity futures returns. It is therefore the simple average for each month of the excess returns for those commodity futures that were traded in that month. The period of calculation, which ends in December 2006, differs across commodities because the starting month varies. We take the starting month to be the latest of: the first month of the inventory series, the 12th month since the futures contract for the commodity started to trade, and December 1969.[5] We require a 12-month trading history because later in the paper we will examine the role of prior 12-month returns. We require the starting month to be December 1969 at the earliest because before 1970 we have only two commodities (Cocoa and Soybeans) for which both futures price data and inventory data are available. The third column indicates the first month of the sample for the commodity. The fourth column of the table lists the number of monthly observations in our sample.

Columns 5-9 of the table have statistics of the excess returns. Although the sample period is slightly different than in Gorton and Rouwenhorst (2006), these summary statistics are qualitatively similar to their study. Of the 33 sample commodities 26 (21) earned a positive risk premium over the sample as measured by the sample arithmetic (geometric) average excess return. An equally-weighted index earned an excess return of 5.48% per annum. The next columns show that the return distributions of commodity futures typically are skewed to the right and have fat tails. DL (1992) make similar observations concerning the distribution of commodity spot prices. Columns 10 and 11 indicate that commodity futures excess returns are positively

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[5] Natural Gas is exempted from this rule. Natural Gas futures started trading in April 1990. The starting month for Natural Gas is nevertheless set to December 1990, because we wish to include this important commodity in the sub-sample of December 1990-December 2006 to be examined later in Tables 5-8.

correlated (on average) with the returns on other commodity futures, but the correlations are on average low (0.12). The average correlation of individual returns with the return on the equally-weighted index is 0.40.

Finally, the last column of the table shows that the sample average (percentage) basis has been negative for two-thirds of the commodities.[6] An equally-weighted portfolio of the sample commodities had an average basis of −2.10%, indicating that on average across commodities and time periods futures prices have exceeded contemporaneous spot prices. Otherwise stated, on average, commodity futures markets have been in "contango." At the same time, the average excess return on the equally-weighted index has been positive (5.48% per annum), indicating a historical risk premium to the long side of a commodity futures position.

These observations are of interest, because the futures basis is often referred to by practitioners as the "roll-yield" of a commodity futures position, and a positive roll yield ("backwardation") is sometimes viewed as a requirement for the existence of a positive risk premium to a long position in commodity futures markets. This view is typically based on arguments such as that portrayed in Figure 1. Figure 1 plots the average basis against the average return on individual collateralized futures during the 1991–2006 period. Figure 1 suggests a connection between the risk premium and commodity characteristics, as measured by the basis. A simple linear regression has an R-squared of 52%.

In our discussion of equations (1) and (2) in Section 2, we already observed that these are not mutually exclusive: the futures basis compares futures prices to contemporaneous spot prices, while the risk premium in equation (2) is the difference between futures prices and expected future spot prices. Equation (1) shows that for commodities to be stored, futures prices have to exceed contemporaneous spot prices to compensate inventory holders for the full cost of storage. Only when inventories are sufficiently low can the spot price exceed the futures price corrected for the cost of carry, i.e. when the convenience yield is sufficiently high. The sample average basis of −2.10% simply indicates that inventories have been sufficiently high on average for the convenience yield not to exceed the full cost of storage. At the same time futures prices have been set at a discount to average future spot prices, rewarding the long side of the futures position for providing price insurance. [7]

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[6] The basis is calculated for each commodity as (F1/F2 -1) * 365/(D2 – D1), where F1 is the nearest futures contract and F2 is the next nearest futures contract; D1 and D2 are the number of days until the last trading date of the respective contracts. The period over which the sample is calculated for the basis is from the month indicated in third column of the table to November 2006, so the sample size is the same as that for the excess return.

[7] A reference to financial futures may be instructive in this context, as financial futures do not have a convenience yield. When the dividend yield on equities is below the interest rate, equity futures price will

However compelling Figure 1 may seem at first glance, it does not directly speak to the presence of risk premiums because the basis and futures returns are ex-post correlated even when ex-ante risk premiums are zero. To see this, imagine a temporary negative shock to the supply (or a positive shock to the demand) of a commodity in a world where risk premiums are zero, and futures prices simply reflect expectations about future spot prices. This negative shock to supply will unexpectedly increase both spot and futures prices, but increase spot prices more than futures prices – reflecting expectations that inventories will be restored over time and spot prices will revert to their mean. In this event, a positive futures return coincides with an increase of the basis. By symmetry, during periods of positive supply shocks, futures returns will be low during periods when the basis falls. Ex-post, therefore, commodities with a high sample average basis are also expected to have high realized average returns. In what follows, we analyze these issues.

The relationship between the basis and ex-ante risk premiums is the subject of Section 5, in which we examine the predictive power of the basis for risk premiums, and the extent to which this predictability stems from variation in inventory levels. In the next sub-section we will present our inventory data.

3.2 Inventory Data

There are many issues involved in compiling a dataset on inventories, the least of which is the absence of a common data source. In addition to data availability, there is the important conceptual question of how to define the relevant inventories. Because most commodity futures contracts call for physical delivery at a particular location, futures prices should reflect the perceived relative scarcity of the amount of the commodity which is available for immediate and future delivery at that location. For example, data on warehouse stocks of industrial metals held at the exchange are available from the LME, but no data is available on stocks that are held off-exchange but that could be economically delivered at the warehouse on short notice. Similarly, relevant crude oil inventories would include not only physical stocks held at the delivery point in Cushing, Oklahoma, but also oil which is held at international locations but that could be economically shipped there, or perhaps even government stocks. Aside from the definition of relevant inventories there is a timing issue. Information about inventories is often published with a lag and subsequently revised. This creates a timing issue in matching variation of prices to variation of inventories. Despite these potential caveats, the behavior of inventories is central to

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exceed spot prices, and the markets will be in “contango” This is not incompatible with the presence of a positive equity risk premium.

the Theory of Storage, and for this reason it is important to attempt to document the empirical relationship between measured inventories and futures prices.

We collected a sample of inventory data for the 33 individual commodities of Table 1 from a variety of sources. With the exception of Sugar, Feeder Cattle, and Rough Rice, we were able to find monthly data for all commodities. For Feeder Cattle, we do not use the available inventory series, which is quarterly. Instead we use 3-month-ahead values of the Live Cattle inventory for the current monthly level of Feeder Cattle, under the assumption that it takes three months to feed calves to create what are called Feeder Cattle. A detailed description of these data is in Appendix B. In the rest of the paper, we will drop Sugar and Rough Rice and focus on the 31 commodities with monthly inventory data.

Examination of the data reveals that the inventory time-series of most commodities contains a time-trend and exhibits strong seasonal variation. We estimated individual inventory trends by applying a Hodrick-Prescott filter to the log of inventories for individual commodities. We will sometimes refer to the Hodrick-Prescott (HP) filtered inventory data as the “normal” inventory level and denote it by I*.[8]

To illustrate the seasonal variation of commodity inventories around these trends we ran a regression of the deviations of the log of inventories from their HP-fitted trends on monthly dummy variables. Table 2 reports the regression results along with the autocorrelation of the residuals (which are de-trended and de-seasonalized inventories). The table helps to illustrate two stylized facts about inventories. First, inventory levels are persistent. At 0.71 inventories of Soybean Meal have the lowest sample first-order autocorrelation, and the median first-order autocorrelation exceeds 0.90. Second, there are large cross-sectional differences in the seasonal behavior of inventories. This is illustrated in Figure 2, which shows the seasonal variation of inventories of Natural Gas, Wheat, and Corn. The seasonal variation of inventories stems from both demand and supply. Many agricultural commodities are harvested once a year and inventories are held to meet demand throughout the year. Inventories therefore are lowest just prior to the harvest season and peak at the end of the harvest season. For example, Corn is

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[8] The smoothness parameter we use when applying the Hodrick-Prescott filter to monthly series is determined as follows. Ravin and Uhlig (2002) recommend adjusting the smoothness parameter in proportion to the fourth power of the relative frequency. So if x is the smoothness parameter for a quarterly series, the monthly equivalent is x times 3^4 (=81). In business cycle analysis, it is customary to use 1,600 for quarterly series. As shown in Ravin and Uhlig (2002), this amounts to retaining peak-to-peak cyclical movements of roughly 10 years or longer, so the difference between the raw series and the filtered series consists of movements of relatively short durations. One would think that determinants of a normal inventory, such as storability and production flexibility, change only gradually. If so, the smoothness parameter should be larger. From visual inspection, we chose a smoothness parameter of 160,000 (whose monthly equivalent is this times 81). This amounts to retaining peak-to-peak cyclical movements of about 30 years or longer.

harvested in late summer to fall in North America. Wheat is harvested in the early summer in the Southern states in the U.S., and in late summer in the Northern states. Wheat inventories therefore are lowest just prior to the harvest season and peak at the end of the harvest season. Contrary to Corn and Wheat, Natural Gas is produced throughout the year, but heating demand has a strong seasonal component which peaks during the winter months. During months of low demand, Natural Gas is stored in underground salt domes. Industrial Metals inventories exhibit little seasonal variation as exhibited by the low regression R-squared given in the table. Crude oil is demanded and produced during the year, but demand for its derivatives --- Heating Oil and Unleaded Gas --- is more seasonal. Because Soybean Oil and Soy Meal are derived commodities and can be produced throughout the year, they exhibit less seasonality than the inventories of Soybeans themselves.

4. Inventories and Futures Prices

This section provides empirical evidence about the relationship between (1) inventory levels and risk premiums of commodity futures and (2) between inventories and the basis. In Section 4.1 we test the central prediction of the Theory of Storage that the marginal convenience yield as proxied for by the basis is a declining function of inventories. This motivates the use of the basis as a measure of the state of inventories. Section 4.2 examines the link between inventories and risk premiums.

4.1. Basis and Inventories

As a preliminary test, we examine whether the futures basis varies between high and low inventory months. Let I and I* indicate the actual and normal inventory level at the end of the month.[9] For each commodity we calculate the average basis for months when the normalized inventory I/I* (the ratio of actual to normal inventory levels) is below 1 and above 1. The results are summarized in Figure 3. The figure illustrates that for all commodities low inventory months are associated with above average basis for that commodity and that the basis is below average during high inventory months. As indicated by the red line, the difference is statistically significant at the conventional 5% level for most commodities. (The calculation of the *t*-values is explained in Appendix C.1.)

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[9] For simplicity we have omitted time subscripts, but keep in mind that the normal inventory level changes through time.

To further explore the non-linear relationship between the basis and inventories we estimate the following non-linear relationship:

$$\mathit{Basis} = \text{linear function of seasonal dummies} + h(x) + \text{error},$$

where x is the normalized inventory level I/I*. The hypothesis is that as inventory levels fall below "normal," as measured by I*, the basis increases at an increasing rate. To allow for this nonlinearity we applied the "cubic spline regression" technique (see. e.g., Green and Silverman (1994) for a textbook treatment). This is a technique for estimating potentially nonlinear functions. Splines are piece-wise polynomial functions that fit together at "knots." In the case of cubic splines, the first and second derivatives are continuous at the knots.[10]

To test whether the basis is negatively related to inventories and whether the relationship is, in fact, nonlinear, we will estimate the slope, implied by the spline function $h(x)$ at the average level of inventories (I = I*) as well as in situations when inventories fall 25% below average (I/I* = 0.75). For each commodity, the sample period is the same as shown in Table 1. The results of these tests are summarized in Table 3, and illustrated in Figure 4 for Copper and Crude Oil.

The second and third columns of Table 3 show that at the average level of inventories (i.e., at I=I*), the estimated slope of the basis-inventory regression is negative for all commodities except one, and statistically significant for more than half of the commodities. For each commodity group, using pooled OLS we estimate the coefficients under the constraint that they are the same within groups. Inspection of the size of the coefficients shows that the relationship is particularly strong for commodities in the Energy group (the pooled OLS estimate for Energy is –154.6), while many Industrial Metals tend to have slope coefficients that are relatively small in magnitude (the pooled OLS estimate is –5.1). Industrial Metals are relatively easy and cheap to store, and equilibrium inventories of Industrial Metals are expected to be large on average relative

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[10] The internal breakpoints that define the piecewise segments are called "knots." Let x_j ($j = 1,2,...,J$, $0 < x_1 < x_2 < ... < x_J$) be so-called "knots". The cubic spline technique approximates $h(x)$ by: $h(x) \approx \beta_1 x + \beta_2 x^2 + \beta_3 x^3 + \sum_{j=1}^{J} \beta_{3+j}(x - x_j)^3 1\{x > x_j\}$, where $1\{\}$ is the indicator function. By construction, the second derivative of $h(x)$ is continuous at each knot. The attraction of a cubic spline is that the approximating function is linear in powers of x . We experimented with J on our data, and decided to set $J = 1$ and set x_1 to be 1 (i.e., $I = I^*$). For larger values of J , there were too many peaks and troughs in the estimated cubic spline.

to demand. By comparison, Energy, which is more bulky and expensive to store, should have lower inventories relative to demand. Cross-sectional differences in storability should therefore be reflected in the sensitivity of the basis to inventory shocks. Perishability also helps to explain why the slope coefficients for Meats are on average larger than for commodities in the Softs and Grains groups. Because storage costs provide an incentive to economize on inventories, it is also expected that the variation of inventories is lower for commodities that are difficult to store, relative to commodities that are easy to store: this is illustrated in the two panels of Figure 4, which shows much larger variation in the inventories of Copper than in the inventories of Crude Oil.

To examine the non-linearity of the basis-inventory relationship, the fourth column of Table 3 reports the slope when inventories fall by 25% from their average value. In the case of Copper, for example, the estimated slope measured at the average level of inventories equals –3.2 (t = –0.61) and steepens to –15.3 (t = –2.76) when inventories drop by 25%. This difference of 12.1, given in column 6, is significant at the 5% level (t = 5.64). Inspection of columns 6 and 7 shows a pattern of steepening slopes for many commodities in the Metals, Grains, and Softs group. The results are weaker for Meats and Energies. Inspection of the inventory data for energy commodities shows that historical inventories often fluctuate within a narrow range, and in some cases do not fall to the test level of 0.75. Consequently, the slope coefficients at 0.75 are merely polynomial extrapolations of a relationship constructed to fit a different portion of the sample and should be taken with caution. This point is clearly seen from Panel B of Figure 4 for Crude Oil.

Overall our results are not inconsistent with the Theory of Storage.[11] We find that there is a clear negative relationship between normalized inventories and the basis and that for many commodities the slope of the basis-inventory curve becomes more negative at lower inventories levels. And we find steeper slopes at normal inventory levels for commodities that are difficult to store. We turn to the relationship between inventories and risk premiums next.

4.2. Inventories and Futures Risk Premiums

As mentioned previously, the Theory of Storage due to Deaton and Laroque (1992) does not make direct predictions about futures risk premiums, but instead makes predictions about the future volatility of spot prices. This prediction stems from the fact that when inventories are low, the ability of inventories to absorb shocks to demand and supply is diminished, raising the conditional volatility of future spot prices. In our model, to the extent that the risk premium on

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[11] The results of Table 3 are not significantly altered if the dependent variable is the interested-adjusted basis; see Equation (1).

long futures positions is compensation paid by hedgers to obtain insurance against price risk, the mean excess return from commodity futures should increase when future spot price risk increases. Therefore, the Theory of Storage implies that the state of inventory at the end of the month is a key predictor of the excess return from the end of the month to the next and that the mean excess return and inventory are inversely related.

As a first test of this prediction, we perform a linear regression of the monthly excess return from the end of month *t*-1 to *t* on I/I* measured at the end of month *t-1* as well as monthly dummies. The Theory predicts that I/I*, our measure of the state of inventories, should have a negative effect on the subsequent excess returns. The results are reported in Table 4. Unlike in the basis-on-inventory regression of Table 3, we only consider the linear specification because the excess return is a hard variable to predict, as evidenced in the low R-squared in Table 4. As is apparent from the low *t*-values, the I/I* coefficients are not sharply estimated. However, most of them have the expected negative sign. If we impose the restriction of a common slope coefficient within groups, we find marginally significant negative slope coefficients for Meats and Energy. These groups also exhibit a larger sensitivity of returns to inventories, which is consistent with our findings in Table 3 that futures prices of commodities that are difficult to store are more sensitive to inventory shocks than commodities that are relatively easy to store.

In a second test, we examine the results of a simple sorting strategy, whereby at the end of each month we cross-sectionally rank the commodities based on their level of normalized inventories. The number of available commodities at the end of each month increases over time because the start date, shown in the third column of Table 1, differs across commodities. At the end of the first month (December 1969), for example, there are seven available commodities. We compare the average return of a portfolio of commodities in the top half in terms of normalized inventories to the average return of a portfolio comprised of the commodities in the bottom half of this ranking. This test has the additional attractive features that it controls for the cross-sectional dependence and, as it is nonparametric, it allows for a non-linear relationship between inventories and the risk premium.

The results are given in Table 5. The returns of the inventory-sorted portfolios are consistent with the predictions of the theory that low inventories are associated with high future risk premiums. Panel A summarizes the returns to these portfolios in deviation from the equally-weighted index. The first columns show that the Low Inventory portfolio has outperformed the High Inventory portfolios in 56% of the months between 1969 and 2006. The annualized average out-performance was 8.06 % (*t* = 3.19). The next columns show that the performance difference between the inventory-sorted portfolios has been relatively stable during the more recent periods of January 1986-December 2006 and December 1990-December 2006.

In Panel B of Table 5, we summarize various characteristics of the commodities in the inventory sorted portfolios: for reasons we will discuss in greater detail in the next section, we report the average prior 12-month futures return prior to portfolio formation, the average percentage 12-month change in spot prices (as measured by the nearest-to-maturity futures price), the average futures basis and the average commodity volatility during the month of the futures return (defined as the standard deviation of daily futures excess returns). The Low Inventory portfolio selects commodities with a high basis: the difference between the basis of the Low and High Inventory portfolios exceeds 12% (t = 14.51). This is, of course, a direct implication of the Theory of Storage, and consistent with our earlier findings in Table 3, and Figure 3. In addition to having a higher basis, Low Inventory commodities also have higher prior spot and prior futures returns than High Inventory commodities. Over the full sample, the 12-month futures return difference prior to inclusion in the portfolio is about 15% per annum (t = 6.45). The high prior futures return of the Low Inventory portfolio suggests that our portfolio sorts capture more than variation of inventories that is predictable. High prior futures returns are an indication of past negative shocks to supply and/or positive shocks to demand. Because inventories cannot be replenished instantaneously, the prior futures return history carries information about the current state of inventories. We will return to this issue in the next section when we investigate the extent to which inventory dynamics can be responsible for the presence of momentum in commodity futures markets.

Finally, the right hand of Panel B summarizes the Positions of Traders in the inventory-sorted portfolios, as reported by the Commodities Futures Trading Commission (CFTC). These positions will be discussed in more detail in the next section 6 of the paper, but for now note that Commercial traders are net short in commodity futures markets and as a percentage of open interest, that their positions are larger for High Inventory commodities.

Two caveats are in order about our trading rule test. First, the tests do not control for (unknown) publication delays in the release of inventory data. If news about inventories is negatively correlated with contemporaneous spot prices, and inventory data is released with a lag, this will create a negative correlation between innovations to inventories and subsequent spot price innovations. Because futures prices will inherit spot price innovations, the delay of news about inventories will create a correlation between inventories and subsequent futures returns that is unrelated to futures risk premiums. Second, our test does not exploit cross-sectional differences between commodities. Because commodities differ in terms of storability (perishability, bulkiness, and capacity constraints of storage) the Theory of Storage predicts that equilibrium inventory policies will differ across commodities. Furthermore, uncertainty about future demand and supply is also likely to vary across commodities, leading to cross-sectional differences in optimal inventory policies that are positively associated with futures risk premiums.

Absent a structural equilibrium model that includes multiple commodities we have no guide as to how to compare the state of inventories across commodities. Theoretically, the important state variable is the “likelihood of stock-out,” which we have proxied for by using I/I*, the inventory level relative to normal inventories, but this measure does not permit comparisons across commodities. In the next section we will examine three predictions of the Theory of Storage that use price-based measures of the state of inventories that circumvent these difficulties.

5. Price-Based Tests of the Cross-Sectional Variation of Futures Risk Premiums

In the previous section, we provided evidence that the shape of a futures curve, i.e., the basis, reflects information about the state of that commodity’s inventory, and that inventory levels are negatively related to subsequent excess returns to commodity futures. In this section, we discuss three additional and related predictions of the Theory of Storage about spot and futures prices. First, when inventories fall spot prices will increase, signalling the scarcity of the commodity for immediate delivery. High spot prices are therefore a signal of the state of inventories. Second, shocks to current inventories also raise futures prices although not by as much as spot prices reflecting expectations that inventories will be restored over time and spot prices will return to “normal” (and perhaps because the risk premium rises). Hence the futures basis widens. Third, to the extent that inventories are slow to adjust, past demand and supply shocks will persist in current inventory levels. Because unanticipated shocks to demand and supply affect futures prices, the futures return history of a commodity carries information about past demand and supply shocks that may not be fully resolved due to the slow adjustment of inventories. In sum, the level of spot prices, the futures basis, and prior futures returns can be expected to carry information about the current state of inventories, and hence will be correlated with risk premiums.

Panel B of Figure 3 illustrates that the relation between inventories and 12-month prior futures returns for individual commodities. Similar to Panel A, for the basis, we calculate average prior 12-month futures returns for each commodity for months when I/I* is above unity and when I/I* is below 1. The Figure illustrates that for most commodities, high normalized inventories are associated with low futures returns over the prior year, while low inventory states are associated with high prior 12-month futures returns. Taken together, Figure 3 shows that prior futures returns and the basis are informative price-based signals of the level of inventories. To the extent that the level of inventories is relevant for futures risk premiums, as suggested in Table 5, it can be expected that prior futures and spot returns and the basis predict risk premiums on commodity futures. In the remainder of this section we will examine the extent to which these price signals carry information about expected futures returns.

There are two advantages to using observable prices as indicators of the state of inventories. First, price information does not suffer from revisions and publication delays associated with inventory data. Second, using price information opens the potential to exploit cross-sectional differences between expected commodity futures returns. For example, if a particular commodity is difficult or costly to store, then all else equal, the Theory of Storage predicts a lower level of equilibrium inventories. Lower average inventories will make a commodity more susceptible to the risk of stock-outs, and the associated futures contract is expected to have a higher equilibrium risk premium. To the extent that these cross-sectional differences are embedded in the shape of the futures curve such as the basis, we expect our price signals to capture this information about cross-sectional differences in expected futures returns

To quantify the information in price signals about both the cross-sectional and time-series variation in risk premiums, we divide the sample of commodities into halves at the end of each month based on their prior performance and the futures basis. We measure the total futures returns of these portfolios during the month until the last day of the month when we re-sort and rebalance. The portfolios are equally-weighted. The performance and characteristics of the portfolios are given in Tables 6, 7, and 8.

Panel A of Table 6 summarizes the returns on the portfolios formed by sorting based on the basis. Over the full sample period since 1969, the High Basis portfolio outperformed the equally-weighted index by 5.42% annualized ($t = 3.98$) while the Low Basis portfolio underperformed the average commodity by 4.82% ($t = -3.44$). The difference between the High and Low Basis portfolio was positive in 58% of the months and averaged 10.23% annualized ($t = 3.73$).

Panel B of Table 6 reports several characteristics of the basis-sorted portfolios. To the extent that the futures basis carries information about the state of inventories, it can be expected that the High Basis portfolio selects commodities that have below average inventories, high spot prices (measured relative to the same time last year), and high prior 12-month futures returns. And as predicted by DL (1992) High Basis commodities are expected to have relatively high future price volatility. These predictions are indeed borne out by the data: the High Basis portfolio selects commodities with low inventories ($t = -17.08$), high futures returns during the 12-month period prior to portfolio formation ($t = 12.93$), and high spot prices relative to the same time a year prior ($t = 10.45$). Somewhat surprisingly, the difference between the volatility of the commodities is both economically as well as statistically relatively small ($t = 2.13$).

The right two-thirds of Table 6 examines two more recent sub-periods. These panels show that these returns and portfolio characteristics have been relatively stable during the first and second halves of our sample. The last three rows of Panel B summarize the positions of Traders in the basis-sorted portfolios, as reported by the Commodities Futures Trading Commission (CFTC). These will be discussed in more detail in the next section of the paper, but for now note that Commercials are on average net short in both the High and Low Basis portfolios, and Non-Commercials and small (Non-Reportable) traders are net long. Non-Commercials are over-weighted in the High Basis commodities, and the reverse holds for the Non-Reportable positions. There is no significant difference in the positions of Commercials between the two portfolios.

Inspection of the portfolio characteristics suggests that the basis-sorted portfolios capture time-series variation of risk premiums by selecting commodities when inventories are low. However, as pointed out before, differences in the basis can also reflect cross-sectional differences in storability of commodities that is correlated with (unconditional) risk premiums. To examine whether the returns to the basis strategies capture time-series variation of risk premiums or simply select commodities that are difficult to store, we repeated the portfolio sorts after subtracting the full sample mean from the basis for each commodity. This isolates the returns that can be attributed to time-series variation of the basis from return variation attributed to cross-sectional variation in the average basis. Unreported results show that the sample average return difference between High and Low (de-meaned) Basis portfolios is 10.13% ($t = 3.52$), which is not significantly different from the returns associated with sorting on the raw basis. This suggests that the returns of sorting commodities on the raw basis primarily captures time-variation of futures returns that is associated with time variation of inventories.

Table 7 summarizes the returns to sorting commodities on Futures Momentum, measured as the prior 12-month futures return. Although momentum has been documented at horizons ranging from one month to one year, we chose to report results for a relatively long prior return interval (e.g., see Pirrong (2005) and Shen, Szakmary, and Sharma (2007)). Our choice is driven by our goal of constructing a price-based measure of inventories. Based on the empirical evidence of Table 2 that inventories are slow to adjust, we expect relatively distant prior shocks to inventories to carry information about current inventories. Because some commodities have distinct annual seasonal variation in production, we include a history of up to one year in our price-based measure of past positive demand shocks or negative supply shocks. Unreported results show that sorting on longer term measures of past futures returns increases the dispersion between the inventory characteristics of the momentum portfolios.

Panel A shows that High Momentum commodities have outperformed a portfolio of Low Momentum commodity futures by 13.36% per annum (*t* = 4.93), earning positive excess returns in 58% of the months. The point estimates for the excess returns are slightly higher for the second half of the sample, as well as the fraction of the months the excess return is positive (65% since 1990, versus 58% over the full sample). Panel B shows that Momentum portfolios take positions in similar commodities as the Basis-sorted portfolios. In particular, the High Momentum portfolio selects commodities with High Basis and below average inventories, while the Low Momentum portfolio does the opposite. The *t*-statistics associated with these characteristics differences are large and clearly indicate that portfolios sorted on inventories, the basis, and prior performance take correlated positions in ways that are predicted by the Theory of Storage. This is reflected in the correlation between the returns to High Basis and High Momentum portfolios, which is 0.87 over the full sample period. Inspection of the Positions of Traders reveals that Commercials increase their short positions in commodities that experience price increases, while Non-Commercials take larger long positions following a price run-up.

Finally, Table 8 reports the results from sorting commodities based on the change in the year-on-year percentage change of the commodity spot price. In light of the seasonality of spot prices of many commodities the 12-month prior spot return captures the change in the relative scarcity of each commodity compared to the same time a year ago. Panel A of the Table shows that the results for portfolios sorted on Spot Momentum are quantitatively similar to those sorted on Futures Momentum. The High Spot Momentum portfolio has outperformed the Low Momentum portfolio by 13.85 % annualized (*t* = 4.95) over the full sample, and by 16.03% during the last 16 years (*t* = 4.47). And High Spot Momentum commodities have relatively low inventories, high futures momentum, and a high basis. Inspection of the Positions of Traders shows that Commercials hedge more after spot prices have increased and that much of the liquidity to them is provided by the Non-Commercials.

The main conclusion from Tables 5-8 is that, consistent with the predictions of the Theory of Storage developed in Appendix A, risk premiums of commodity futures vary with the state of inventories. Portfolios that take positions based on prior futures return, prior spot returns and the futures basis select commodity futures with below average inventories which the Theory predicts are expected to earn higher risk premiums. Moreover, these risk premiums are highly significant, both in a statistical sense as well as in an economic sense. We also presented some evidence that the Position of Traders varies with the return of the price-based portfolio strategies – especially Momentum and Inventories, although the interpretation of the positions evidence is somewhat ambiguous. Commercials increase their short positions after a price run-up, but also when inventories are high. Non-commercials take larger long positions in commodities with high momentum, and, to a lesser extent, high basis.

In our model in Appendix A, the correlation between inventories and the amount of open interest in the futures market is ambiguous and depends on the relative sensitivities of the risk-averse investors and the inventory holders, seeking to hedge bankruptcy costs. However, the co-movement between the basis, inventories, momentum and traders' positions raises the question of a causal relationship; in particular we are interested whether the positions of market participants can provide an alternative explanation for our results. We explore this issue in more depth in the next section.

6. Risk Premiums and the Positions of Traders

It is difficult to reconcile commodity futures risk premiums with traditional asset pricing models, because historical excess returns to commodity futures have low correlations with equities and aggregate consumption, which are important measures of risk in traditional asset pricing models [e.g., Jagannathan (1985), and Gorton and Rouwenhorst (2006)]. In part for this reason, the prevailing explanation for commodity futures risk premiums in the empirical literature has been hedging-pressure, which is based on the Keynesian Theory of Normal Backwardation. This section re-examines the evidence for the hedging-pressure hypothesis, and tests whether hedging pressure can provide an alternative explanation for the variation of the risk premiums documented in this paper.

In the Keynesian view, the function of commodity futures markets is to enable a risk transfer between hedgers and investors/speculators. The Theory of Normal Backwardation postulates that hedgers are on net short and offer speculators a risk premium by setting futures prices at a discount relative to expected future spot prices. Academic researchers have tested this prediction by examining the relation between futures returns and "hedging pressure" – defined as the relative size of the short positions taken by hedgers. Empirically, hedging pressure is measured using data on positions of large traders published by the CFTC. In the Commitment of Traders Reports large traders are classified as "commercials" or "non-commercials." The CFTC omits information about the specific identities of traders, but it has become customary in the academic literature to view commercials as hedgers and non-commercial as investors.[12] Several papers, including papers by Carter, Rausser, and Schmitz (1983), Chang (1985), Bessembinder (1992), and De Roon, Nijman, and Veld (2000), Dincerler, Khokher and Titman (2003) and Dincerler, Khokher and Simin (2004) show that the relative size of the commercial positions is correlated with futures risk premiums.[13]

The interpretation of the empirical evidence on hedging pressure is complicated by two issues. First, most papers document a *contemporaneous* correlation between futures prices and traders' positions. The contemporaneous correlation may simply reflect the response of traders to changes in futures prices and does not speak to a causal relationship.[14] The first question we ask therefore is whether hedging pressure is correlated with expected *future* commodity risk premiums. Second, these papers treat hedging pressure as exogenous, but it seems reasonable to assume that traders' positions reflect an equilibrium response to demand and supply shocks to physical commodity markets. For example, when a negative supply shock drives down inventories and increases current spot and futures prices, hedgers might find it advantageous to hedge more in equilibrium, despite the fact that the compensation they have to offer to speculators has increased due to increased uncertainty about future spot prices. Therefore, the second question of interest is: if hedging pressure predicts ex-ante risk premiums, to what extent does this reflect an optimal response to fundamental shocks?

Table 9 provides a summary of the net positions of traders. [15] For each commodity we report the average net long position by trader category, the standard deviation of the position, the percentage of the months the position is long, as well as the persistence of the position as measured by the first-order autocorrelation coefficient (rho). All positions are measured as a fraction of the total open interest in that commodity. The first observation about Table 9 is that commercials are on average net short in most markets, while non-commercials and non-reportable positions are on average net long. This is broadly consistent with the Keynesian hypothesis. Exceptions include Corn, Feeder Cattle, Lean Hogs and Milk, where the average

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[12] In addition, the CFTC has a category of "non-reportable positions," which includes either commercial or non-commercial positions that are below the reporting limits set by the CFTC. These would include either small hedgers or speculators. For the exact definitions see http://www.cftc.gov/opa/backgrounder/opacot596.htm. See also Ederington and Lee (2002) for a discussion about the accuracy of the classifications.

[13] See also Van der Goorbergh (2004) and Szymanowska (2006). Bryant, Bessler and Haigh (2006) question the hedging pressure hypothesis.

[14] De Roon, et al (2000) is the only paper to examine the correlation between returns and ex-ante hedging pressure, but we were unable to qualitatively replicate their results. They appear to be studying the contemporaneous correlation. Our results are similar to Wang (2003).

[15] The CFTC does not cover LME commodities, and there in insufficient data for Butter and Coal which are also excluded from Table 9.

position of the commercials is net long. If all short positions were taken up by commercials, their average position would be 100% of the open interest. Instead, the average net short position of commercials across commodities is about 10%, which indicates that commercials are both long and short in a given month. In addition, the table shows that there are large cross-sectional differences in net positions over time: the average standard deviation of the net position of commercials in column 4 of Table 9 is 15% per month. Also, there are large cross-sectional differences across commodities. For example, commercials in Oats and Platinum are short more than 90% of the months, while the Crude Oil and Corn commercials are almost equally likely to be long or short. Non-Reportable positions in Coffee are always net long, while non-reportable positions in Corn and Feeder Cattle are almost always short. Positions are uniformly persistent for all commodities: the first-order autocorrelations of the positions of commercials range from 0.59 for Coffee to 0.92 for Palladium. It is notable that the non-reportable positions are on average net long in most contracts and for most of the time. A detailed explanation of these differences is beyond the scope of this paper as our main focus is on the question whether these positions predict risk premiums.

Table 10 summarizes the results of regressions of futures excess returns on hedging pressure, defined as the net long position of commercials scaled by the open interest as in Table 9. Hedging pressure enters this regression either contemporaneously or predictively: in the left columns of each panel the monthly futures return between *t–1* and *t* are regressed on the hedging pressure measured at time *t*, in the right columns hedging pressure is measured at the at time *t–1*. A negative slope coefficient in the table means that an increase in hedging (decrease of long position) by commercials is associated with a higher futures return. The results in Table 10 show that the slope coefficients are generally significantly negative when hedging pressure is measured at the end of the return interval (i.e., contemporaneously), but insignificantly different from zero when hedging pressure is measured at the beginning of the return interval (i.e., lagged). The R-squared of the predictive regressions is on average below 1%, compared to 10% on average in the coincident regressions. These results are therefore inconsistent with the hypothesis that hedging pressure is an important determinant of ex-ante risk premiums, and consistent with a story that traders adjust their positions as futures prices change.[16] In particular, the significantly negative slope coefficients in the coincident regressions indicate that commercials increase their short positions as prices go up, while non-commercials increase their long positions in a rising market.

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[16] We also conducted a sort of commodities into portfolios based on beginning of period hedging pressure, along the same lines as the portfolio sorts in tables 5-8. Unreported results show that we find no evidence that these sorts were informative about spreading futures risk premiums.

This would make non-commercials appear to be momentum investors. Indeed, the results in Tables 7 and 8 which summarize the characteristics of portfolios sorted on prior futures or prior spot price returns indicate that non-commercials take larger long positions in high momentum commodities than in commodities with poor prior performance.

The main conclusion of this section is that contrary to the existing literature, we find no evidence that supports a hedging pressure explanation for risk premiums in commodity futures markets. Instead, we have shown that risk premiums systematically vary with the state of inventories, as predicted by the Theory of Storage. Two questions remain. First, does our single factor explanation capture most of the predictable variation of risk premiums? And second, can we reconcile these risk premiums with modern asset pricing theories of risk?

Answering these questions is beyond the scope of the current paper, but we leave the reader with partial answers to these questions. We have shown that portfolios sorted on basis and momentum take positions in low inventories. If we regress the excess returns of High Basis portfolio on the excess return of the Low Inventories portfolio, we find a significant intercept of 2.4% p.a. (t = 1.58). A similar regression of the excess returns of High Momentum portfolio on the excess returns of the Low Inventories portfolio has an intercept of 4.0% p.a. (t = 2.27). This suggests that there is an orthogonal component to the returns to basis and momentum portfolios that is not captured by variation of inventories. This may be due to a combination of noise in the measurement of inventories, or that our inventory sorts do not capture cross-sectional differences in inventory dynamics across commodities that are correlated with risk premiums. Alternatively, it may be due to an omitted risk factor that drives both the returns to basis and prior-return sorted portfolios. If we run a regression of the components of the returns to basis and momentum portfolios that are orthogonal to inventories on each other, we find that the resulting intercept of that regression to be insignificantly different from zero, both economically as well as statistically. This suggests that basis and momentum portfolios contain a common source of risk that is orthogonal to variation in inventories, and is compensated for in average returns. We leave a full exploration of these issues to future research.

7. Summary and conclusions

This paper examines the relationship between the state of inventories and risk premiums of individual commodity futures, as predicted by the Modern Theory of Storage. For this purpose, we collect a comprehensive historical monthly dataset of inventories for 31 individual commodities over a 37-year period between 1969 and 2006. Our major findings can be summarized as follows. First, consistent with the predictions of the Theory of Storage, we empirically document a negative, non-linear relationship between the futures basis (convenience yield) and the level of inventories: at low inventory levels the basis increases at an increasing rate. Second, we show that the state of inventories is informative about futures risk premiums. Although inventory data suffer from measurement error, we show that commodity futures and spot prices carry relevant information about the state of inventories that can be used to provide additional evidence about the role of inventories for futures risk premiums. In particular we show that prior futures returns, prior spot price changes and the futures basis are correlated with futures risk premiums as predicted by the Theory. Finally, we distinguish our explanation of risk premiums from the Theory of Normal Backwardation, which – in its empirical implementation – attributes risk premiums to "hedging pressure" by Commercial hedgers. While the positions of participants in futures markets vary with both returns and the state of inventories, we find no evidence that the positions of futures traders predict risk premiums on commodity futures.

Appendix A: Storage and Commodity Futures

Deaton and Laroque (1992) present an infinite horizon model of intertemporal inventory dynamics with risk neutral agents. The goal of their model is to explain spot commodity price dynamics, in particular, the extreme volatility of spot commodity prices, and the prevalence of pronounced upward price spikes with no downward spikes, resulting in high positive skewness. The model is not about futures markets, and futures markets are not included. In Section 1 of this Appendix we present a simple two period version of Deaton and Laroque. In Section 2 we add a commodity futures market to the model.

A1. A Two-Period Deaton and Laroque Model

There is a single good in the economy, the "commodity." There are three dates, t=0, t=1, and t=2 and two classes of agents in the economy. There are inventory holders who sell the commodity and who want to maximize t=2 wealth, denominated in dollars. Inventory holders sell the commodity to commodity buyers, who want units of the commodity and pay dollars to obtain these units. Commodity buyers' preferences are defined over the commodity.

We consider the storage decision of a representative, competitive, risk neutral, inventory holder. At t=0 the inventory holder has on hand an amount z_0 of the single good in the economy. At t=1 the inventory holder will receive a random endowment of the single good, z_1, drawn from f(z), which has support $[\underline{z}, \bar{z}]$. Commodity buyers' demand for the commodity at dates 1 and 2 is summarized by D(p). Prices at dates 1 and 2 are p_0 and p_1, respectively. The price of the commodity is expressed in terms of dollars per unit of commodity. The demand function is a continuously differentiable, monotonically decreasing function of price. There is a constant returns to scale storage technology available to the inventory holder, but goods depreciate so that one unit stored at t=0 yields (1–δ) units at t=1, where $0<\delta<1$. The interest rate is zero.

Before the t=0 goods market opens the inventory holder chooses an amount of inventory, I_0, to carry over to t=1. So, at t=0 the amount available for sale in the commodity market is $z_0 - I_0$. At t=1, the inventory holder receives the realization z_1 and so the amount available for sale in the t=1 goods market is $z_1 + I_0(1-\delta)$.

At t=0 the representative inventory holder chooses I_0, taking prices as given, to maximize expected dollar profits:

$$\text{Max } \Pi_0 = p_0(z_0 - I_0) + E[p_1(z_1 + I_0(1-\delta))] \quad \text{s.t. } I_0 \geq 0. \qquad \text{(A1)}$$

Deaton and Laroque emphasize the constraint that the inventory must be nonnegative, i.e., goods from the future, t=1 (z_1), cannot be sold earlier, at t=0. For example, if z_0 is very low, e.g., zero, then the inventory holder would like to sell more at t=0, but cannot.

An equilibrium is a set of prices, p_0 and p_1 such that (i) the goods markets at t=0 and t=1, respectively, clear; and (ii) the inventory holders' profits are maximal. Deaton and Laroque point out that profit maximization implies the following "no arbitrage" conditions:

$$I_0 = 0 \text{ if } (1-\delta)E(p_1) < p_0$$

$$I_0 \geq 0 \text{ if } (1-\delta)E(p_1) = p_0.$$

In words, inventories, I_0, are zero if there is an expected loss from holding them. Inventory holders will hold inventory only if there is an expected profit from doing so, and they will increase their holdings until current and future expected prices are equated.[17] Deaton and Laroque combine the above “no arbitrage” profit maximization conditions with market clearing to obtain an expression for the equilibrium price process (in an infinite horizon setting). They then prove that there exists a unique rational expectations price function.

We proceed to solve for the equilibrium in a different way, with an eye toward adding a commodity futures market in the next section. Solving recursively, consider the goods market at t=1. At that date there are no decisions to be made, as this is the last goods market and so there is no point to storing goods any further. The inventory holder simply puts all his remaining goods on the market. Market clearing implies:

$$D(p_1) = z_1 + (1 - \delta)I_0.$$

This determines the equilibrium price (inverse demand) as: $p_1^* = \Gamma_1(z_1 + (1-\delta)I_0)$.

Now we turn to date t=0. The market at this date must also clear, for any level of commodity inventory chosen by the inventory holder. So, for given I_0:

$$D(p_0) = z_0 - I_0,$$

which yields the equilibrium price (inverse demand) in the first commodity market $p_0^* = \Gamma_0(z_0 - I_0)$. For equilibrium prices we will use the notation Γ_0 and Γ_1, suppressing the arguments of these functions unless needed for clarity. Note that Γ_0 and Γ_1 are continuously differentiable, monotonically decreasing functions of the quantity supplied on the market.

Substituting the market-clearing equilibrium prices into the inventory decision problem at t=0, the inventory holder chooses I_0 to maximize:

$$\text{Max } \Pi_0 = \Gamma_0(z_0 - I_0) + E[\Gamma_1(z_1 + I_0(1 - \delta))] \quad \text{s.t. } I_0 \geq 0$$

where the arguments of the equilibrium price functions Γ_0 and Γ_1 have been suppressed.

Since the representative inventory holder is a price taker, the first order condition is:

$$E[\Gamma_1(1 - \delta)] = \Gamma_0 - \lambda \qquad \text{(A2)}$$

where λ is the Lagrange multiplier on the non-negativity constraint on I_0. E(*) is the expectation operator taken over uncertainty with respect to z_1.

If the non-negativity constraint is binding, then $I_0 = 0$. Otherwise, $\lambda = 0$ and there is a positive amount of inventory carried forward. In other words, equation (A2) results in the same Deaton and Laroque arbitrage conditions for inventories. So, the solution to (A2) gives the equilibrium value of I_0 as a function of the market clearing prices. Substituting that value into the market

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[17] Like Deaton and Laroque, we ignore any exogenously assumed “convenience yields.” Routledge, Seppi, and Spatt (2000) show how the nonnegativity constraint leads to an endogenous convenience yield in the Deaton and Laroque model with risk neutral futures traders.

clearing price equations determines the prices. This completes the determination of the equilibrium.[18]

Deaton and Laroque (1992) also prove that the variance of Γ_1 is decreasing in I_0 and increasing in Γ_0, a result that will be important below.[19]

A2. Storage Dynamics and Commodity Futures

We now introduce a commodity futures market which opens at t=0 and settles at t=1. The futures exchange specifies that one unit of the good corresponds to one futures contract. In the futures market at t=0 there is a price $F at which the two trading parties agree to trade. F will be determined in equilibrium. The parties agree at t=0 that the "long" investor will pay $F per contract to the "short" investor at t=1. In exchange, the short investor agrees at t=0 to deliver one unit of the commodity to the long investor at t=1 for each contract entered into at t=0.

We assume that futures contracts must be fully collateralized for the "long" investor, so that a purchase of N futures contracts at price $F, per contract, requires $NF to be set aside in an account at the futures exchange at t=0.[20]

We also now introduce a large number of competitive, risk averse, speculators, each with utility defined over second period wealth (measured in dollars), U(W), where U'>0 and U''<0. Each speculator receives an endowment of e_0 dollars at date t=0.

At t=0 the representative speculator chooses a futures position $N^L F$ by "going long" N^L futures contracts. Settlement in the futures market occurs at t=1 just before trade in the second period goods market. So, the long investor will take delivery of N units of the commodity and sell that amount in the goods market, receiving dollars. The risk faced by the long investor is that the price of the commodity in the second period commodity market is low, exactly the risk that the inventory holder seeks to hedge.

Inventory holders have a hedging demand, N^S, because we now assume that they face a bankruptcy cost. That is, inventory holders want to go "short" futures in order to hedge the price risk emanating from the randomness of z_1. For simplicity, we write the bankruptcy cost in reduced form as the function $g(z_1, I_0, NF)$, where the first partial derivatives are all negative, i.e., the likelihood of incurring the bankruptcy cost is declining as z_1, I_0, or hedging increase. I_0 and N are endogenous choice variables of the inventory holder, while z_1 is an exogenous variable realized at t=1. The price F is determined in equilibrium. For simplicity, we assume that all second derivatives and cross partials are zero.[21]

Implicitly, bankruptcy corresponds to second period profits falling below a threshold (a debt level). Since the only source of uncertainty is z_1, bankruptcy corresponds to a realized value of z_1 below a critical value. That critical value depends on I_0 and the amount of hedging. Intuitively, the risk faced by the inventory holder is that the z_1 realization is low. Holding a higher level of inventory, I_0, serves as a buffer against this possibility. Similarly, the futures market provides a

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[18] See Deaton and Laroque (1992) for a formal derivation.

[19] See Lemma 4 in the Appendix of Deaton and Laroque (1992), p. 22.

[20] We assume fully collateralized futures for long investors for simplicity. The alternative is to impose a bankruptcy cost and associated constraint that takes into account the possibility that a futures long investor might not be able to honor the futures contract at t=1.

[21] Without this assumption further assumptions would have to be made about the size of these effects, in the proof of the proposition below.

way to hedge this risk. Thus, we intentionally omit details, but assume that bankruptcy is less likely to occur to the extent that the inventory holder has more inventory to sell in the second market and has hedged the price risk associated with second period sales.

The bankruptcy cost is to be thought of as a reduced form for a variety of motivations for firms to hedge that have been discussed in the literature.[22] Our goal is only to provide a parsimonious motivation for a hedging demand.

Discussion of the Model

Futures contracts are not redundant in the model, as inventory holders' behavior will change, in that their intertemporal allocation of goods between periods one and two will differ from the case where there is bankruptcy cost and no futures markets, and the case where there are bankruptcy costs and there is a futures market. The likelihood of incurring the bankruptcy cost declines if inventories are higher, but it may be cheaper to hedge the bankruptcy risk in the futures market rather than increase inventories. In the presence of the bankruptcy cost, the futures market is welfare improving, although we cannot formally demonstrate this because the agents demanding the goods in the two periods are not formally modeled.

Also, note that the inventory holder is engaged in "cost-of-carry arbitrage." If holding inventory until next period, and foregoing this period's price while incurring the depreciation cost, is lower than the expected price next period, then the inventory holder should engage in that transaction – except that the expected bankruptcy cost must be taken into account. There are no agents in the model who can engage in cost of carry arbitrage without facing the expected bankruptcy cost.

The speculators are a distinct group from the agents who are implicitly modeled by the demand functions each period. Again, this is for simplicity. As will be seen, it allows for goods market to clear independently of the speculators' behavior.

The risk faced by a long investor in the futures market is the price risk of the second period goods market, where the long investor sells goods received to settle the futures contracts. We leave open the question of whether this risk is systematic or idiosyncratic, but we assume that the risk averse speculator cannot diversify this risk.

Equilibrium with a Futures Market

At t=0 the (representative) speculator uses some of his endowment to "buy" \$$N^LF$ futures, i.e., N^L contracts each at price \$F. Recall that, by assumption, his futures position must be fully collateralized. He sets that amount aside as collateral (at the futures exchange), leaving him with $e_0 - N^LF$ dollars at t=0 which he stores until t=1. In equilibrium $N^L = N^S$; we sometimes omit the superscript. At t=1 he receives his collateral back, but uses that to settle his futures position. He pays NF dollars and receives N units of the commodity, which he can sell in the goods market at the equilibrium price of Γ_1 per unit, i.e., N Γ_1 is the value of what he receives. Summarizing, at t=1 his wealth is:

$$W = (e_0 - NF) + N\Gamma_1 = e_0 + N(\Gamma_1 - F).$$

Let N^L be the number of futures contracts the speculator is willing to go long at t=0 at price F. Then at t=0 the speculator's problem is to choose N^L to:

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[22] See, e.g., Getzy, Minton, and Schrand (1997) and Graham and Smith (1999).

$$\text{Max } E[U(W)] \text{ s.t. } W = e_0 + N^L(\Gamma_1 - F).$$

The first order condition is:

$$E[U'(\Gamma_1 - F)] = 0 \text{ or } E[U'(\frac{\Gamma_1 - F}{F})] = 0 \qquad \text{(A3)}$$

Note that $\Gamma_1 - F$ is the (realized) risk premium on the futures position. If things go well for the futures investor, this will be positive, but the futures position is risky and this term might turn out to be negative. The first order condition values the risk premium with the pricing kernel U' (which here is trivial as it is a one-period problem). The first order condition makes clear that the speculator must be rewarded for taking risk, as the utility function is concave. He increases his futures position until there is no further expected gain to doing so.

Turning to the inventory holder, let N^S be the number of contracts the inventory holder is willing to go short at t=0. This is the number of units of the commodity that the inventory holder must deliver to physically settle his futures position at maturity, t=1. In exchange, he receives \$NF. The inventory holder chooses I_0 and N^D to:

$$\text{Max } \Pi_0 = p_0(z_0 - I_0) + E[p_1(z_1 + I_0(1-\delta) - N^S) + N^S F] - E[g(z_1, I_0, N^S F)]$$

$$\text{s.t. } I_0 \geq 0.$$

A Rational Expectations Equilibrium is a set of prices Γ_0, Γ_1 and F such that: (i) the goods markets at t=0 and t=1 clear; (ii) the futures market at t=0 clears, i.e., $N^L = N^S = N$; (iii) inventory profits are maximal; and (iv), the speculator's utility is maximal.

As before, we start at t=1. The amount supplied in the second period goods market consists of the inventory holder's final inventory, net of what was used to settle his futures position, $z_1 + (1 - \delta)I_0 - N$, plus the amount of goods delivered to the speculator in the futures market, N. So the goods market clearing condition is:

$$D(p_1) = z_1 + [(1-\delta)I_0 - N] + N = z_1 + [(1-\delta)I_0 \equiv I_1,$$

which yields $p_1^+ = \Gamma_1(I_1)$ (i.e., the inverse of the demand function).

Given I_0 and the initial endowment, z_0, at t=0 the goods market clears if:

$$D(p_0) = z_0 - I_0,$$

which implies that $p_0^+ = \Gamma_0(z_0 - I_0)$ is the equilibrium price. As above, we will use the notation Γ_0 and Γ_1 for equilibrium prices, respectively, suppressing the arguments of these functions.

Given the equilibrium prices in the goods markets, Γ_0 and Γ_1, respectively, at t=0 the price-taking inventory holder chooses I_0 and N^S to:

$$\text{Max } \Pi_0 = \Gamma_0(z_0 - I_0) + E[\Gamma_1(z_1 + I_0(1-\delta) - N^S) + N^S F] - E[g(z_1, I_0, N^S F)]$$

$$\text{s.t. } I_0 \geq 0.$$

The first order conditions with respect to I_0 and N^D, respectively, are:

$$E[\Gamma_1(1-\delta)] = \Gamma_0 - \lambda + E(g'_{I_0}) \tag{A4}$$

$$\frac{E[\Gamma_1 - F]}{F} = -E(g'_N)\,, \tag{A5}$$

where λ is the Lagrange multiplier on the non-negativity constraint on inventories. Recall that the partial derivatives of the bankruptcy function are negative, i.e., expected marginal bankruptcy costs are decreasing if inventories or hedging increase.

Equation (A4) alters the Deaton and Laroque "no arbitrage" condition. Now there is an incentive to hedge against the bankruptcy cost even if expected profits from carrying inventory are negative at the margin. Holding more in inventory makes incurring the bankruptcy cost less likely. If there is an interior solution where $I_0>0$, then $\lambda=0$, which will henceforth assume is the case.

Equation (A5) expresses the risk transfer function of the futures market. The expected risk premium, earned by the speculator, is $E[\Gamma_1 - F]$. Since the right-hand side of (A5) is positive (the partial derivative is negative), the expected risk premium paid to the speculator, $E[\Gamma_1 - F]$, is positive. However, the inventory holder does not mind if the risk premium is expected to be positive, i.e., an expected net positive payment to the speculators, because it helps reduce the expected bankruptcy cost. It is also instructive to write (A5) as:

$$F = \frac{E(\Gamma_1)}{1 - E(g'_N)}\,.$$

Since the partial derivative is negative, it is clear that in equilibrium (i.e., evaluating (A5) at the equilibrium values) F will be set at a discount to the expected future spot price, where the discount is a function of the expected bankruptcy cost. In this sense, the model displays Keynesian "normal backwardation."

We have already determined the market clearing goods prices, as functions of the inventory decision, I_0, an endogenous variable. Equation (A4) determines the equilibrium level of inventories, I_0. The futures market must also clear, i.e., $N^L = N^S = N$. The supply of futures contracts is determined by equation (A3) and the demand for futures contracts is determined by equation (A5). Equation (A3) (substituting in the equilibrium value Γ_1) and equation (A5) jointly clear the futures market by determining N and F. Solving (A5) for F and substituting into (A3), eliminating F, gives an expression implicitly determining the equilibrium N:

$$E[U'\Gamma_1]\left(1 - \frac{\partial E(g)}{\partial N}\right) = E[U']E[\Gamma_1]\,. \tag{A6}$$

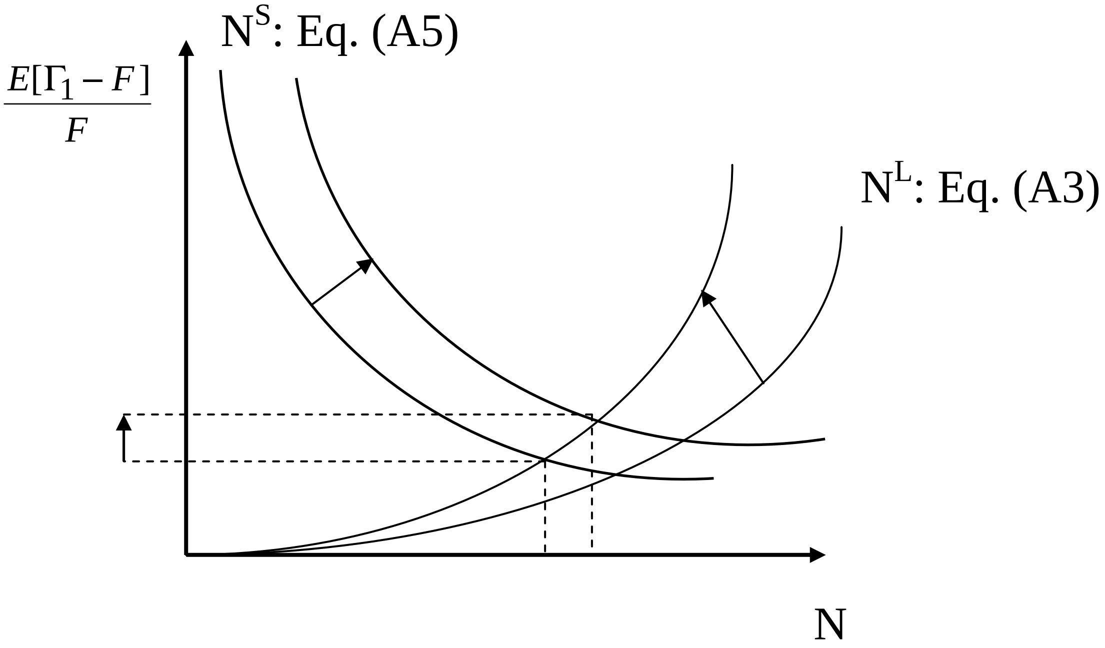
This completes determination of the equilibrium.

Some Results

The source of the risk premium in the futures market is the risk premium in the spot market. Comparing the inventory holder's first order conditions (A2) and (A4), it is clear that the inventory holder requires a higher expected return on holding inventory intertemporally due to the presence of the bankruptcy cost. Just as the equity risk premium is inherited by S&P futures, so the commodity futures inherit the risk premium in the spot commodity prices.

The fundamental state variable of commodity futures is the level of inventories. To see this consider a reduction in inventories due to an exogenous shock (alternatively this can be thought of as an exogenous change in net demand), i.e., z_0, is reduced. When this occurs the expected risk premium rises. The result of Deaton and Laroque that the variance of Γ_1 is decreasing in I_0 and increasing in Γ_0 still holds. Since the variance of the second period spot price (the risk borne by the long investors and shed by the short investors) increases when inventories go down, the expected risk premium in the futures market (the compensation paid to the long investor by the short investor) rises. This can be seen from the demand for the long position, N^L, by the investors (Equation (A3)), and the demand to short, N^S, by the inventory holders (Equation (A5)). This is shown in the figure below.

The Expected Risk Premium Rises When Inventories Fall



But, note that while the expected risk premium rises when inventories fall, the equilibrium number of futures contracts, N, may rise or fall (though the figure shows N rising). This depends on the relative curvature of the demand and supply functions for long and short futures positions. This ambiguity will be important when we analyze the positions of traders in the main text.

When inventories, z_0, decline, the basis, $\Gamma_0 - F$, increases. To see this first notice that we have the following results due to the properties of the inverse demand function:

$$\frac{\partial \Gamma_0}{\partial z_0} < 0; \quad \frac{\partial \Gamma_0}{\partial I_0} > 0; \quad \frac{\partial E(\Gamma_1)}{\partial I_0} < 0 .$$

So, Γ_0 increases. Then for the basis to increase when inventories decline, either F must go down or, at least, not rise by as much as Γ_0. We know that ${dE(\Gamma_1)}\big/{dI_0} < 0$. Looking at equation (A5), we can see what happens to F in equilibrium when z_0 declines. Since the bankruptcy costs display constant marginal costs (by assumption), F must also go down when I_0 goes down. Equation (A4) determines the equilibrium level of inventories. Note that it depends on the equilibrium number of futures contracts and on the equilibrium futures price because those are arguments of the g function. The total differential is:

$$(1-\delta)^2 \frac{\partial E(\Gamma_1)}{\partial I_0} dI_0 - \frac{\partial \Gamma_0}{\partial I_0} dI_0 - \frac{\partial \Gamma_0}{\partial z_0} dz_0 = 0 .$$

Recall that we have assumed constant marginal costs. This can be rewritten as:

$$\frac{dI_0}{dz_0}\left((1-\delta)^2 \frac{\partial E(\Gamma_1)}{\partial I_0} - \frac{\partial \Gamma_0}{\partial I_0} \right) = \frac{\partial \Gamma_0}{\partial z_0}$$

which implies that $dI_0 / z_0 > 0$ because $\partial E(\Gamma_1) / \partial I_0 < 0$; $\partial \Gamma_0 / \partial I_0 > 0$; and $\partial \Gamma_0 / \partial z_0 < 0$. This shows that the basis widens when inventories go down.

As in RSS (2000), there is an endogenous implied “convenience yield” that arises just as RSS showed.

Appendix B: Inventory Data

1. **Aluminum:** Source: London Metals Exchange: "Warehouse stocks." Start date: 12/29/1978. Periodicity: daily.

2. **Butter:** Source: U.S. Department of Agriculture: "Commercial stocks of butter in the U.S. on first of the month in thousands of pounds." Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month.

3. **Coal:** Department of Energy: Monthly Energy Review: "U.S. Coal stocks." Start date: 03/31/1999. Periodicity: monthly. At the time of writing, the data was not available for December 2006. The value for this month is assumed to be equal to the November 2006 value.

4. **Cocoa:** Source: New York Board of Trade, sum of three series: "Visible stocks of cocoa in New York warehouses" (thousands of bags), same for Philadelphia warehouses and for Port of Hampton Road warehouses. Data to 04/30/1999 is 1000 times the monthly series of the same data compiled by Commodity Research Bureau (CRB Yearbooks CD) in millions of bags and rounded to one decimal place. Start date: 1/31/1931. Periodicity: monthly.

5. **Coffee:** Source: New York Board of Trade: "Exchange warehouse stocks, 60 kg bags." Start date: 1/31/1983. Periodicity: monthly.

6. **Copper:** Source: London Metals Exchange. Start date: 1/2/1970. Periodicity: daily.

7. **Corn:** Source: USDA Livestock and Seed Division, Portland OR. "Stocks of Grain at Selected Terminals and Elevator Sites, thousands of bushels." Start date: 06/25/1974. Periodicity: weekly.

8. **Cotton:** Source: New York Board of Trade: "Certificated Warehouse Stocks, 480 lb bales." Start date: 12/31/1989. Periodicity: weekly.

9. **Crude Oil:** Source: Department of Energy: Monthly Energy Review "U.S. crude oil ending stocks non-SPR, thousands of barrels." Start date: 1/31/1945. Periodicity: monthly.

10. **Feeder Cattle:** For Feeder Cattle, we do not use the available inventory series which is quarterly. Instead we use 3-month-ahead values of the Live Cattle inventory for the current monthly level of Feeder Cattle, under the assumption that it takes three months to feed calves to create what are called Feeder Cattle. Source: U.S. Department of Agriculture: "Cold storage holdings of frozen beef in the U.S. on first of the month in thousands of pounds." Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month and then shifted 3 months forward to account for the average time feeder cattle spends in feedlots.

11. **Heating Oil:** Department of Energy: Monthly Energy Review "U.S. total distillate stocks." Start date: 1/31/1945. Periodicity: monthly.

12. **Lead:** Source: London Metals Exchange: "Warehouse stocks." Start date: 1/2/1970. Periodicity: daily.

13. **Lean Hogs:** Source: U.S. Department of Agriculture: "Cold storage holdings of frozen pork in the U.S. on first of the month in thousands of pounds." Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month.

14. **Live Cattle:** Source: U.S. Department of Agriculture: "Cold storage holdings of frozen beef in the U.S. on first of the month in thousands of pounds." Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month.

15. **Lumber:** American Forest & Paper Association: "Stocks (gross) of softwood in the United States, on the first of the month, in millions of board feet." Data compiled by Commodity Research Bureau (CRB Yearbooks CD) and rounded to one decimal place. Start date: 12/31/1969. Periodicity: monthly. Data as of the first of the month is shifted to the end of previous month. At the time of writing, data were not available for June 2006 to December 2006. The values for those months are assumed to be the same as the May 2006 value.

16. **Milk:** Source: U.S. Department of Agriculture: "Commercial stocks of milk in the U.S. on first of the month in thousands of pounds." Start date: 12/31/1969. Periodicity: monthly. Data compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Data as of the first of the month is shifted to the end of previous month.

17. **Natural Gas:** Department of Energy: Monthly Energy Review: "U.S. total natural gas in underground storage (working gas), millions of cubic feet." Start date: 9/30/1975. Periodicity: monthly.

18. **Nickel:** Source: London Metals Exchange: "Warehouse stocks." Start date: 7/13/1979. Periodicity: daily.

19. **Oats:** Source: USDA Livestock and Seed Division, Portland OR. "Stocks of Grain at Selected Terminals and Elevator Sites, thousands of bushels." Start date: 06/25/1974. Periodicity: weekly.

20. **Orange Juice:** Source: U.S. Department of Agriculture: "Cold storage stocks of orange juice concentrate in the U.S., millions of pounds." Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled by Commodity Research Bureau (CRB Yearbooks CD) from National Agricultural Statistics Services (NASS-USDA) data and rounded to 1 decimal place. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month.

21. **Palladium:** Source: New York Mercantile Exchange: “Warehouse stocks.” Start date: 10/31/1995. Periodicity: daily.

22. **Platinum:** Source: New York Mercantile Exchange: “Warehouse stocks.” Start date: 10/31/1995. Periodicity: daily.

23. **Pork Bellies:** Source: U.S. Department of Agriculture: “Frozen pork belly storage stocks in the United States, on first of the month, in thousands of pounds.” Start date: 12/31/1969. Periodicity: monthly. Data to 12/31/2004 is compiled in an Excel table by Economic Research Services (ERS-USDA) from National Agricultural Statistics Services (NASS-USDA) data. Then, the data is taken directly from NASS-USDA monthly Cold Storage reports. Data as of the first of the month is shifted to the end of previous month.

24. **Propane:** Source: Department of Energy: Monthly Energy Review: “U.S. ending stocks of Propane/Propylene, thousands of barrels.” Start date: 1/31/1971. Periodicity: monthly.

25. **Soybeans:** Source: USDA Livestock and Seed Division, Portland OR. “Stocks of Grain at Selected Terminals and Elevator Sites, Thousands of Bushels”. Start date: 06/25/1974. Periodicity: weekly. From 12/31/1961 to 05/31/1974 1000 * monthly series of the same data compiled (in millions of bushels) by Commodity Research Bureau (CRB Yearbooks CD) and rounded to 1 decimal place as “Commercial stocks of soybeans in the United States, on the first month, in millions of bushels.” and shifted to the end of previous month.

26. **Soybean Oil:** Source: Economic Research Services, U.S. Department of Agriculture: “Stocks of soybean oil (crude and refined) at factories and warehouses in the United States on the first of month, millions of pounds. Data compiled by Commodity Research Bureau (CRB Yearbooks CD) and rounded to 1 decimal place. Start date: 9/30/1970. Periodicity: monthly. Data as of the first of the month is shifted to the end of previous month.

27. **Soybean Meal:** Source: Economic Research Services, U.S. Department of Agriculture: “Stocks, including mill feed and lecithin of soybean cake and meal at oil mills in the United States on the first of the month in thousands of short tons.” Data compiled by Commodity Research Bureau (CRB Yearbooks CD) and rounded to 1 decimal place. Start date: 9/30/1970. Periodicity: monthly. Data as of the first of the month is shifted to the end of previous month.

28. **Tin:** Source: London Metals Exchange: “Warehouse stocks.” Start date: 1/2/1970. Periodicity: daily. Gap in the data from Jan. 1986 – 6/30/1989 during the suspension of trading due to tin crisis. Contract resumed trading in June 1989, but it took another 12 months or so for warehouse stocks to rise from extremely low levels. We only used data from 6/30/1990.

29. **Unleaded Gas:** Source: Department of Energy: Monthly Energy Review: “U.S. total motor gasoline ending stocks, thousands of barrels.” Start date: 3/31/1981. Periodicity: monthly.

30. **Wheat:** Source: USDA Livestock and Seed Division, Portland OR. “Stocks of Grain at Selected Terminals and Elevator Sites, Thousands of Bushels”. Start date: 06/25/1974. Periodicity: weekly. From 06/30/1970 to 05/31/1974 1000 * monthly series of the same data compiled (in millions of bushels) by Commodity Research Bureau (CRB Yearbooks CD) and rounded to 1 decimal place as “Commercial stocks of domestic wheat in the United States, on the first month, in millions of bushels of domestic wheat in storage in public and private

elevators in 39 markets and wheat afloat in vessels or barges at lake and seaboard ports, the first Saturday of the month." and shifted to the end of previous month.

31. **Zinc:** Source: London Metals Exchange: "Warehouse stocks." Start date: 1/2/1970. Periodicity: daily.

Appendix C: Details of Estimation Procedures

This appendix is in two parts, describing the procedures for calculating two sorts of statistics employed in the paper. The first part concerns the *t*-statistics for the mean. It has two paragraphs. The first, which is about the *t*-statistics for scalar time series with serial correlation (shown in Tables 5-8), is fairly standard, but is described here for completeness and as a lead-in to the second paragraph, where calculation of the *t*-statistics for the difference in the two sample means (shown in Figure 3) is discussed. The second part is about the standard errors and *t*-statistics of the pooled OLS coefficients on an unbalanced panel when the errors are serially correlated. The *t*-values based on those standard errors appear in Tables 3 and 4.

C1. *t*-statistics for the Mean of a Serially Correlated Series

Let $\{y_t\}$ be the serially correlated scalar time series and let $\bar{y} = \frac{1}{n}\sum_{t=1}^{n} y_t$ be the sample mean. We wish to calculate the *t*-statistics for testing the null hypothesis that the population mean of the series is zero. Under suitable assumptions (see, e.g., Hayashi (2000, Chapter 6.5)), we can show that, under the null,

$$\sqrt{n}\bar{y} \xrightarrow[d]{} \mathrm{N}(0, \mathrm{Avar}(\bar{y})),$$

where $\mathrm{Avar}(\bar{y})$, sometimes called the *long-run variance*, is given by

$$\mathrm{Avar}(\bar{y}) = \gamma_0 + 2\sum_{j=1}^{\infty}\gamma_j = \sum_{j=-\infty}^{\infty}\gamma_j, \quad \gamma_j \equiv \mathrm{E}(y_t y_{t-j}).$$

The so-called Newey-West estimate of the long-run variance is:

$$\mathrm{Est.Avar}(\bar{y}) \equiv \sum_{j=-q}^{q}\left(1 - \left|\frac{j}{q+1}\right|\right)\hat{\gamma}_j, \quad \hat{\gamma}_j \equiv \frac{1}{n-j}\sum_{t=j+1}^{n} y_t y_{t-j}.$$

Under suitable conditions, this is a consistent estimator of $\mathrm{Avar}(\bar{y})$. Therefore, we have a *t*-ratio for the sample mean that is asymptotically standard normal:

$$t \equiv \frac{\sqrt{n}\bar{y}}{\sqrt{\mathrm{Est.Avar}(\bar{y})}} \xrightarrow[d]{} \mathrm{N}(0,1).$$

This is the *t*-statistics displayed in Tables 5-8.

The *t*-statistics graphed in Figure 3 in red is the *t*-statistics for the following difference in the sample means created by two time series $\{x_t, z_t\}$:

$$\frac{1}{\#\{t \mid z_t \geq 1\}}\sum_{t\in\{t|z_t\geq 1\}} x_t - \frac{1}{\#\{t \mid z_t < 1\}}\sum_{t\in\{t|z_t< 1\}} x_t = \frac{1}{n}\sum_{t=1}^{n} y_t,$$

where $\#\{t \mid z_t \geq 1\}$ is the cardinality of the set $\{t \mid z_t \geq 1\}$ and

$$y_t \equiv \left(\frac{1}{\hat{\mu}}1\{z_t \geq 1\} - \frac{1}{1-\hat{\mu}}1\{z_t < 1\}\right)x_t, \quad \hat{\mu} \equiv \frac{\#[t \mid z_t \geq 1\}}{n},$$

(In Panel A of Figure 3, for example, x_t is the basis and z_t is the normalized inventory.) So, as in the previous paragraph, the difference in sample means can be written as a sample average of a given series y_t. However, since each observation of the series $\{y_t\}$ here depends on a common random variable $\hat{\mu}$, the long-run variance of the sample mean of y_t will involve the asymptotic variance of $\hat{\mu}$ if $\hat{\mu}$ converges to its population mean μ only at the usual rate of $\sqrt{n}$. We ignore this possible complication by assuming that the convergence of $\hat{\mu}$ is faster than $\sqrt{n}$. This is a reasonable assumption to make in the context of Figure 3 because by construction z_t (the normalized inventory) is above 1 for almost half the time.

C2. Calculating Standard Errors of pooled OLS Estimates

The system of equations estimated in Tables 3 and 4 can be written as

$$y_{mt} = z_{mt}{}'\delta + \varepsilon_{mt} \qquad (m = 1,2,...,M; t = 1,2,...,n) \tag{C1}$$

where t denotes the period and m denotes the commodity, with M being the number of commodities. z_{mt} $(L \times 1)$ is the L-dimensional vector of regressors in the m-th equation for period t. In the case of Table 3, for example, z_{mt} consists of 16 variables: the 12 monthly dummies, x_{mt}, $x_{mt}{}^2$, $x_{mt}{}^3$, and $(x_{mt} - 1)^3 1\{x_{mt} > 1\}$, where x_{mt} is the ratio of actual to normal inventory level for commodity m at the end of month t. For now, assume the sample is a balanced panel in that (y_{mt}, z_{mt}) is observable for any pair (m,t).

The pooled OLS estimator of δ is

$$\underset{(L\times 1)}{\hat{\delta}} = \left[\sum_{m=1}^{M}\left(\sum_{t=1}^{n} z_{mt} z_{mt}{}'\right)\right]^{-1} \sum_{m=1}^{M}\left(\sum_{t=1}^{n} z_{mt} y_{mt}\right) = \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt} z_{mt}{}'\right)\right]^{-1} \sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt} y_{mt}\right). \tag{C2}$$

Substituting (1) into (2), we obtain

$$\sqrt{n}(\hat{\delta} - \delta) = \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt} z_{mt}{}'\right)\right]^{-1} \sum_{m=1}^{M}\left(\frac{1}{\sqrt{n}}\sum_{t=1}^{n} z_{mt}\varepsilon_{mt}\right) = \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt} z_{mt}{}'\right)\right]^{-1} F'\left(\frac{1}{\sqrt{n}}\sum_{t=1}^{n} g_t\right) \tag{C3}$$

where

$$\underset{(ML\times L)}{F} \equiv \begin{bmatrix} I_L \\ I_L \\ \vdots \\ I_L \end{bmatrix}, \quad \underset{(ML\times 1)}{g_t} = \begin{bmatrix} z_{1t}\varepsilon_{1t} \\ z_{2t}\varepsilon_{2t} \\ \vdots \\ z_{Mt}\varepsilon_{Mt} \end{bmatrix}. \tag{C4}$$

Under suitable conditions (stated in, e.g., Hayashi (2000, Chapter 6.5)), $\sqrt{n}(\hat{\delta} - \delta)$ has a limiting normal distribution whose variance is given by:

$$\underset{(L\times L)}{\text{Avar}(\hat{\delta})} = \left[\text{E}\left(z_{mt} z_{mt}{}'\right)\right]^{-1} F' \underset{(ML\times ML)}{\text{Avar}(\bar{g})} F \left[\text{E}\left(z_{mt} z_{mt}{}'\right)\right]^{-1}, \tag{C5}$$

where $\text{Avar}(\bar{g})$, the long-run variance of $\bar{g} \equiv \frac{1}{n}\sum_{t=1}^{n} g_t$, is the variance of the limiting distribution of $\frac{1}{\sqrt{n}}\sum_{t=1}^{n} g_t$. It can be expressed as:

$$\underset{(ML\times ML)}{\text{Avar}(\bar{g})} = \sum_{j=-\infty}^{\infty} \Gamma_j = \Gamma_0 + \sum_{j=1}^{\infty}\left(\Gamma_j + \Gamma_j{}'\right), \tag{C6}$$

where Γ_j is the *j*-th order autocovariance matrix of $\{g_t\}$:

$$\Gamma_j \equiv \text{E}\left(g_t g_{t-j}{}'\right) \qquad (j = 0, \pm 1, \pm 2, ...). \tag{C7}$$

Since $\{g_t\}$ is as in (4) above, the autocovariance Γ_j is a partitioned matrix given by:

$$\underset{(ML\times ML)}{\Gamma_j} = \begin{bmatrix} \text{E}(\varepsilon_{1t}\varepsilon_{1,t-j}z_{1t}z_{1,t-j}{}') & \text{E}(\varepsilon_{1t}\varepsilon_{2,t-j}z_{1t}z_{2,t-j}{}') & \cdots & \text{E}(\varepsilon_{1t}\varepsilon_{n,t-j}z_{1t}z_{M,t-j}{}') \\ \text{E}(\varepsilon_{2t}\varepsilon_{1,t-j}z_{2t}z_{1,t-j}{}') & \text{E}(\varepsilon_{2t}\varepsilon_{2,t-j}z_{2t}z_{2,t-j}{}') & \cdots & \text{E}(\varepsilon_{2t}\varepsilon_{M,t-j}z_{2t}z_{M,t-j}{}') \\ \vdots & \cdots & \cdots & \vdots \\ \text{E}(\varepsilon_{Mt}\varepsilon_{1,t-j}z_{Mt}z_{1,t-j}{}') & \text{E}(\varepsilon_{Mt}\varepsilon_{2,t-j}z_{Mt}z_{2,t-j}{}') & \cdots & \text{E}(\varepsilon_{Mt}\varepsilon_{M,t-j}z_{Mt}z_{M,t-j}{}') \end{bmatrix} \tag{C8}$$

$$= \left(\text{E}(\varepsilon_{mt}\varepsilon_{h,t-j}z_{mt}z_{h,t-j}{}')\right)_{m,h}$$

That is, the (*m*,*h*) block of Γ_j is the $L\times L$ matrix $\text{E}(\varepsilon_{mt}\varepsilon_{h,t-j}z_{mt}z_{h,t-j}{}')$.

The Newey-West estimator of $\text{Avar}(\bar{g})$ is

$$\underset{(ML\times ML)}{\text{Est.Avar}(\bar{g})} \equiv \sum_{j=-q}^{q}\left(1 - \left|\frac{j}{q+1}\right|\right)\hat{\Gamma}_j, \tag{C9}$$

where $\hat{\Gamma}_j$ is a consistent estimate of Γ_j to be specified below. The parameter q in (C9) is sometimes called the *bandwidth*. With $\text{Avar}(\bar{g})$ thus estimated, we can estimate $\text{Avar}(\hat{\delta})$ as

$$\underset{(L\times L)}{\text{Est.Avar}(\hat{\delta})} = \left[\sum_{m=1}^{M}\frac{1}{n}\sum_{t=1}^{n} z_{mt}z_{mt}{}'\right]^{-1} F' \underset{(ML\times ML)}{\text{Est.Avar}(\bar{g})}\, F \left[\sum_{m=1}^{M}\frac{1}{n}\sum_{t=1}^{n} z_{mt}z_{mt}{}'\right]^{-1}. \tag{C10}$$

The (asymptotic) standard error of the pooled OLS estimate is the square root of $\frac{1}{n}$ times the corresponding diagonal element of this matrix. The *t*-value is the ratio of the point estimate to this standard error.

To calculate $\text{Est.Avar}(\hat{\delta})$, we need to estimate $\hat{\Gamma}_j$'s, which are $ML\times ML$ matrixes of fourth moments. For the case of the Metals group in Table 3, we have $M=8$ and $L=16$, so $ML=128$. The finite-sample property of the *t*-value might be better if we impose conditional homoskedasticity of the errors (so $\text{E}(\varepsilon_{mt}\varepsilon_{h,t-j}\,|\,z_{mt}, z_{h,t-j}) = \text{E}(\varepsilon_{mt}\varepsilon_{h,t-j})$). Under conditional homoskedasticity, we can write Γ_j in (8) as products of second moments:

$$\underset{(ML\times ML)}{\Gamma_j} = \left(\text{E}\left(\varepsilon_{mt}\varepsilon_{h,t-j}\right)\text{E}\left(z_{mt}z_{h,t-j}\right)\right)_{m,h}. \tag{C11}$$

The natural estimator of this, which replaces population means by sample means and the unobserved error terms by pooled OLS residuals, is

$$\underset{(ML\times ML)}{\hat{\Gamma}_j} = \left(\frac{1}{n}\sum_{t=1}^{n}\hat{\varepsilon}_{mt}\hat{\varepsilon}_{h,t-j}\,\frac{1}{n}\sum_{t=1}^{n} z_{mt}z_{h,t-j}\right)_{m,h}, \tag{C12}$$

where $\hat{\varepsilon}_{mt}$ is the pooled OLS residual

$$\hat{\varepsilon}_{mt} \equiv y_{mt} - z_{mt}{}'\hat{\delta}\,.$$

To recapitulate, for balanced panels, the pooled OLS point estimate is (C2) and its asymptotic variance $\text{Est.Avar}(\hat{\delta})$ is estimated by (C10) with $\text{Est.Avar}(\bar{g})$ given by (C9) and (C12).

We now turn to our treatment of missing observations. In the case of Tables 3 and 4, the period from which (y_{mt}, z_{mt}) is observable depends on *m*. That is, (y_{mt}, z_{mt}) is observable only for $t = s(m), s(m)+1, ..., n$, where $s(m)$ is the first period of observation. The sample is an unbalanced panel in this sense. The pooled OLS estimator pools all the available observations in one sample, so:

$$\underset{(L\times 1)}{\hat{\delta}} = \left[\sum_{m=1}^{M}\left(\sum_{t=s(m)}^{n} z_{mt} z_{mt}{}'\right)\right]^{-1} \sum_{m=1}^{M}\left(\sum_{t=s(m)}^{n} z_{mt} y_{mt}\right). \tag{C2'}$$

The expression for $\text{Est.Avar}(\hat{\delta})$ is similarly modified so that the averages over *t* are averages over available terms. Thus, (C10) becomes

$$\underset{(L\times L)}{\text{Est.Avar}(\hat{\delta})} = \left[\sum_{m=1}^{M}\frac{1}{n-s(m)+1}\sum_{t=s(m)}^{n} z_{mt} z_{mt}{}'\right]^{-1} F' \underset{(ML\times ML)}{\text{Est.Avar}(\bar{g})}\, F \left[\sum_{m=1}^{M}\frac{1}{n-s(m)+1}\sum_{t=s(m)}^{n} z_{mt} z_{mt}{}'\right]^{-1} \tag{C10'}$$

and (C12) becomes

$$\underset{(ML\times ML)}{\hat{\Gamma}_j} = \left(\frac{1}{n-N(m,h,j)+1}\sum_{t=N(m,h,j)}^{n} \hat{\varepsilon}_{mt}\hat{\varepsilon}_{h,t-j}\, \frac{1}{n-N(m,h,j)+1}\sum_{t=N(m,h,j)}^{n} z_{mt} z_{h,t-j}{}'\right)_{m,h} \tag{C12'}$$

where $N(m,h,j) = \max\{s(m), s(h)+j\}$.

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Table 1: Summary of Commodity Futures Returns 1969/12-2006/12

The table summarizes the average excess returns to individual commodity futures, expressed as percent per annum. Column 3 gives the first month of the sample period for the commodity in question. Column 4 gives the number of monthly observations in the sample, followed by the arithmetic and geometric average returns. The next columns give the annualized volatility (defined as the standard deviation of monthly excess return multiplied by the square root of 12), skewness, and kurtosis of the monthly return distribution, followed by the average pair-wise correlation with the other sample commodities and an equally-weighted index that includes all commodities. The final column gives the average futures basis, measured as the percentage difference between the nearest and next-to-maturity futures contracts and expressed as a percent per annum.

Commodity Group	Commodity	Start	N	Arithm Mean	Geom. Mean	Stdev	Skew	Kurt	Corr w/ Others	Corr w/ Index	Avg Basis
Index	Index	196912	444	5.48	4.58	13.5	0.91	8.71	0.40	1.00	-2.10
Metals	Copper	196912	444	7.77	4.06	27.7	0.77	6.10	0.19	0.40	0.37
	Platinum	199510	134	12.82	11.28	17.6	-0.16	2.83	0.12	0.33	2.59
	Palladium	199510	134	13.41	6.76	37.2	0.60	4.89	0.09	0.25	-0.11
	Zinc	198901	215	3.77	1.17	23.2	0.71	4.21	0.14	0.35	-3.51
	Lead	198901	215	4.90	2.18	23.7	0.69	4.05	0.11	0.28	-3.22
	Nickel	198802	226	16.65	9.37	41.5	3.06	25.99	0.14	0.40	2.67
	Aluminum	198806	222	-2.06	-3.93	19.3	-0.11	4.03	0.16	0.41	-4.09
	Tin	199007	197	4.11	2.39	18.9	0.88	5.76	0.14	0.37	-1.54
Softs	Cotton	198912	204	-4.10	-7.64	26.7	0.27	3.46	0.08	0.22	-7.30
	Cocoa	196912	444	5.94	0.89	32.5	0.83	4.62	0.07	0.27	-1.86
	Sugar	198912	204	6.78	2.71	28.6	0.09	3.20	0.07	0.20	3.18
	OJ	196912	444	4.58	0.11	31.3	2.01	14.87	0.03	0.16	-3.97
	Lumber	197010	434	0.50	-3.95	30.0	0.42	4.34	0.09	0.19	-7.61
	Coffee	198301	287	2.17	-4.95	38.9	1.09	5.71	0.07	0.21	-5.83
Grains	Wheat	197006	438	-0.80	-3.84	25.0	0.79	5.91	0.15	0.52	-5.02
	Corn	197406	390	-5.42	-8.06	23.4	1.12	9.34	0.18	0.57	-9.76
	Soybeans	196912	444	3.31	-0.52	28.6	1.70	13.54	0.20	0.70	-2.80
	Soybean Oil	197009	435	7.49	2.46	33.1	1.64	9.79	0.16	0.60	0.02
	Soybean Meal	197009	435	6.80	1.46	34.6	2.55	21.08	0.18	0.65	-0.72
	Oats	197406	390	-2.02	-6.77	32.6	2.83	27.67	0.13	0.49	-7.91
	Rough Rice	198708	232	-6.35	-10.48	29.4	1.19	8.40	0.07	0.18	-13.06
Meats	Pork Bellies	196912	444	1.77	-5.36	38.3	0.58	4.41	0.13	0.44	4.58
	Live Cattle	196912	444	6.37	4.61	18.7	-0.23	4.49	0.14	0.44	1.33
	Lean Hogs	196912	444	7.54	3.81	27.4	0.15	4.35	0.15	0.50	-5.86
	Feeder Cattle	197211	409	2.87	1.37	17.2	-0.53	5.74	0.08	0.32	1.55
	Milk	199701	119	5.14	1.34	28.2	0.87	5.46	0.05	0.12	1.16
	Butter	199709	111	11.03	4.78	36.1	0.68	5.40	0.03	0.11	-7.18
Energies	Heating Oil	197911	325	9.00	4.44	30.7	0.62	4.66	0.15	0.45	2.24
	Crude Oil	198403	273	14.47	8.98	33.7	0.60	5.83	0.13	0.47	5.81
	Gasoline	198512	252	18.35	12.24	36.0	0.90	5.71	0.14	0.51	7.85
	Propane	198808	220	27.03	17.56	48.7	3.95	37.52	0.14	0.52	9.41
	Natural Gas	199012	192	8.67	-5.63	54.5	0.55	3.74	0.10	0.42	-15.66
	Coal	200207	53	-2.53	-4.05	17.6	0.33	2.61	0.17	0.49	-8.45

Table 2: Inventories and Seasonality

The table summarizes results from a regression of de-trended inventories on monthly dummies. De-trended inventories are defined as the percentage deviation from the normal level (i.e., 100 times log(*I*/*I**) where *I* and I* are the levels of actual and normal inventories and log(*I**) is the fitted value of applying a Hodrick-Prescott filter to the log of inventories. The second column gives the start of the time series of inventories for each commodity; the end of the sample is December 2006. Subsequent columns give the estimated dummy coefficients, and the R-squared of the regression. The final column gives the first-order autocorrelation of monthly de-trended inventories

Commodity Group	Commodity Name	Start	N	Coefficients of Monthly Dummies												R-sq	rho
				Jan	Feb	March	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec		
Metals	Copper	196912	445	0.049	0.024	-0.064	-0.045	-0.053	-0.103	-0.064	0.045	0.089	0.044	0.036	0.042	0.01	0.98
	Platinum	199510	135	-0.064	-0.104	-0.056	-0.035	-0.133	-0.157	0.193	0.181	0.208	0.027	-0.031	-0.026	0.05	0.86
	Palladium	199510	135	-0.053	0.094	0.140	-0.094	-0.057	-0.018	-0.163	-0.172	0.023	-0.021	-0.019	0.316	0.01	0.94
	Zinc	196912	445	0.007	-0.010	-0.021	0.004	0.012	-0.001	-0.007	0.033	0.045	0.009	-0.029	-0.041	0.00	0.97
	Lead	196912	445	-0.007	-0.019	-0.040	-0.031	-0.027	0.021	0.044	0.033	0.047	0.023	0.002	-0.045	0.00	0.97
	Nickel	198004	321	0.104	0.028	0.002	0.055	0.081	-0.041	-0.087	-0.096	-0.028	-0.054	-0.031	0.070	0.00	0.96
	Aluminum	197912	325	0.050	0.033	0.015	0.002	-0.029	-0.023	-0.042	-0.023	-0.005	-0.008	0.034	-0.002	0.00	0.98
	Tin	199006	199	0.079	0.020	0.019	-0.013	-0.044	-0.070	-0.050	0.008	-0.010	-0.037	-0.001	0.103	0.01	0.95
Softs	Cotton	198912	205	-0.038	0.207	0.347	0.344	0.283	0.163	0.079	-0.456	-0.572	-0.341	-0.088	0.067	0.12	0.81
	Cocoa	196912	445	-0.094	-0.062	0.000	0.056	0.143	0.159	0.197	0.098	0.025	-0.161	-0.231	-0.126	0.04	0.94
	OJ	196912	445	-0.018	0.103	0.117	0.187	0.268	0.249	0.154	0.019	-0.141	-0.293	-0.378	-0.259	0.49	0.92
	Lumber	196912	445	0.000	0.013	0.018	0.014	-0.009	-0.009	-0.014	-0.014	-0.002	0.007	-0.006	0.001	0.01	0.90
	Coffee	198301	288	-0.104	-0.099	0.065	-0.007	0.132	0.116	0.162	0.105	0.074	-0.164	-0.283	0.003	0.01	0.96
Grains	Wheat	197006	439	-0.005	-0.093	-0.179	-0.312	-0.419	-0.193	0.114	0.260	0.305	0.263	0.164	0.069	0.34	0.96
	Corn	197406	391	0.300	0.273	0.233	0.126	-0.070	-0.248	-0.397	-0.489	-0.342	0.065	0.290	0.284	0.42	0.91
	Soybeans	196912	445	0.372	0.316	0.252	0.116	-0.067	-0.246	-0.473	-0.796	-0.848	0.378	0.526	0.459	0.61	0.76
	Soybean Oil	197009	436	0.063	0.067	0.074	0.079	0.072	0.034	0.017	-0.052	-0.138	-0.133	-0.080	0.007	0.07	0.97
	Soybean Meal	197009	436	0.050	0.034	0.019	0.047	0.082	-0.021	0.034	-0.142	-0.184	-0.025	0.061	0.049	0.07	0.71
	Oats	197406	391	0.086	0.026	-0.036	-0.126	-0.266	-0.321	-0.237	0.013	0.213	0.270	0.216	0.154	0.12	0.94
Meats	Pork Bellies	196912	445	0.207	0.239	0.438	0.572	0.618	0.489	0.054	-0.646	-1.211	-0.825	-0.150	0.209	0.70	0.87
	Live Cattle	196912	445	0.078	0.042	0.035	0.012	-0.030	-0.053	-0.052	-0.058	-0.044	-0.012	0.020	0.060	0.09	0.92
	Lean Hogs	196912	445	0.007	0.030	0.078	0.173	0.166	0.075	-0.045	-0.168	-0.163	-0.086	-0.030	-0.036	0.30	0.91
	Feeder Cattle	196912	445	0.013	-0.030	-0.053	-0.052	-0.058	-0.044	-0.012	0.020	0.061	0.078	0.041	0.035	0.09	0.92
	Milk	197001	444	-0.069	-0.044	-0.029	0.025	0.090	0.121	0.133	0.083	0.016	-0.050	-0.137	-0.139	0.28	0.95
	Butter	197001	444	-0.133	0.005	0.052	0.185	0.291	0.261	0.252	0.134	-0.026	-0.143	-0.409	-0.467	0.23	0.91
Energies	Heating Oil	196912	445	0.020	-0.094	-0.195	-0.210	-0.149	-0.077	0.026	0.091	0.137	0.149	0.171	0.129	0.50	0.92
	Crude Oil	196912	445	-0.015	-0.012	0.010	0.026	0.031	0.017	0.004	-0.011	-0.025	-0.001	0.001	-0.023	0.07	0.94
	Gasoline	196912	445	0.055	0.059	0.024	0.006	0.002	-0.008	-0.018	-0.044	-0.020	-0.039	-0.015	-0.001	0.26	0.85
	Propane	197101	432	-0.178	-0.347	-0.368	-0.248	-0.075	0.059	0.166	0.232	0.263	0.243	0.199	0.055	0.66	0.90
	Natural Gas	197509	376	-0.104	-0.343	-0.473	-0.386	-0.193	-0.025	0.107	0.215	0.311	0.362	0.325	0.167	0.79	0.91
	Coal	199903	94	-0.049	-0.045	-0.002	0.045	0.067	0.059	0.014	-0.028	-0.044	-0.020	0.001	-0.008	0.17	0.94

Table 3: Futures Basis and Inventories

The table reports the results of a regression of the futures basis (measured as the percentage difference between the nearest and next-to-maturity futures contracts and expressed as a percent per annum) on I/I* (the ratio of actual to normal inventory level) and monthly dummies, using a cubic spline regression. The sample period for each commodity is the same as in Table 1. The basis is defined as the annualized difference between the nearest to maturity futures price and the next futures price. Columns 2 to 5 report the slope and associated *t*-statistics of the regression at I/I* = 1 and I/I* = 0.75. The next two columns report the difference in the slopes and a *t*-value for the difference. The standard errors of the coefficient estimates used for calculating the *t*-values are calculated using the Newey-West method for correcting error serial correlation with a bandwidth of 12 months. The estimates reported for each commodity group are the slope and *t*-values when the coefficients of the cubic spline regression are estimated by pooled OLS, which constrains coefficients to be the same across commodities of the same group. The standard errors of the pooled OLS coefficient estimates take into account serial and cross-sectional correlation in the error terms, and the fact that the data is an unbalanced panel, i.e., the starting month differs across commodities.

Commodity	slope at 1	*t*	slope at 0.75	*t*	difference	*t*	R-sq
Metals group	-5.1	-2.46	-11.8	-6.01	6.7	4.70	
Copper	-3.2	-0.61	-15.3	-2.76	12.1	5.64	0.41
Platinum	-3.4	-1.10	-3.1	-0.93	-0.3	-0.12	0.41
Palladium	-4.5	-1.46	-3.2	-1.26	-1.3	-1.03	0.19
Zinc	-1.9	-0.39	-9.6	-2.22	7.6	3.32	0.32
Lead	-14.6	-2.83	-27.0	-5.57	12.4	4.34	0.54
Nickel	-3.9	-1.06	-13.6	-4.13	9.6	5.95	0.55
Aluminum	-5.7	-1.64	-9.4	-2.86	3.7	2.16	0.25
Tin	-0.1	-0.02	-9.3	-3.03	9.2	5.06	0.40
Softs group	-19.3	-5.65	-25.7	-8.37	6.4	4.93	
Cotton	-16.6	-2.62	-24.4	-3.86	7.8	3.51	0.30
Cocoa	-17.1	-2.47	-27.3	-3.47	10.2	3.30	0.31
OJ	-38.9	-3.74	-34.7	-2.75	-4.3	-0.45	0.25
Lumber	-109.1	-2.33	-546.6	-1.97	437.5	1.42	0.33
Coffee	-9.2	-2.17	-16.2	-4.45	7.0	4.98	0.62
Grains group	-21.4	-5.10	-25.1	-5.02	3.7	1.39	
Wheat	-28.7	-3.10	-45.3	-3.48	16.5	1.78	0.28
Corn	-7.2	-0.93	-20.0	-1.91	12.8	1.61	0.31
Soybeans	-24.9	-4.06	-33.1	-4.46	8.2	2.47	0.27
Soybean Oil	-52.1	-3.74	-71.6	-3.75	19.5	1.05	0.29
Soybean Meal	3.5	0.31	18.6	1.29	-15.0	-1.03	0.16
Oats	-12.6	-1.14	-15.5	-1.25	2.9	0.45	0.18
Meats group	-59.8	-7.03	-60.2	-6.27	0.4	0.12	
Pork Bellies	-35.8	-5.94	-39.2	-5.31	3.4	1.17	0.46
Live Cattle	-43.4	-2.34	-9.3	-0.16	-34.1	-0.51	0.18
Lean Hogs	-122.3	-5.34	-64.4	-1.24	-57.9	-0.91	0.62
Feeder Cattle	-14.2	-0.92	-27.8	-0.61	13.7	0.26	0.16
Milk	-63.8	-0.64	-829.9	-2.08	766.1	1.67	0.43
Butter	-51.7	-3.74	-47.2	-2.99	-4.5	-0.54	0.35
Energies group	-154.6	-7.61	-149.6	-4.15	-5.0	-0.16	
Heating Oil	-137.6	-6.03	-99.3	-1.18	-38.2	-0.40	0.59
Crude Oil	-303.9	-6.06	1688.8	0.90	-1992.8	-1.05	0.46
Gasoline	-359.6	-4.11	-1752.7	-0.40	1393.1	0.32	0.50
Propane	-141.0	-5.21	-144.6	-4.61	3.6	0.13	0.56
Natural Gas	-174.9	-2.94	-122.4	-1.93	-52.5	-0.85	0.55
Coal	-64.9	-1.63	-210.8	-0.15	145.9	0.10	0.45

Table 4: Commodity Excess Return and Inventories

The table reports the results of a regression of monthly percentage excess futures returns on de-trended inventories at the start of the month, in addition to monthly dummies. De-trended inventories are defined as I/I*, the ratio of actual to normal inventory levels. Normal inventories are defined as the fitted values of applying a Hodrick-Prescott filter to inventories. The standard errors of the coefficient estimates used for calculating the *t*-values are calculated using the Newey-West method for correcting error serial correlation with a bandwidth of 12 months. The estimates reported for each commodity group are the coefficient and *t*-statistics when coefficients are constrained to be the same.

Commodity	Coefficient of I/I*	*t*	R-sq
Metals group	-0.040	-0.09	
Copper	-0.421	-0.85	0.03
Platinum	-1.071	-1.15	0.10
Palladium	0.767	1.03	0.08
Zinc	-0.398	-0.76	0.04
Lead	-0.504	-0.62	0.03
Nickel	-0.160	-0.28	0.03
Aluminum	0.542	1.58	0.05
Tin	0.779	0.94	0.08
Softs group	-0.240	-0.64	
Cotton	-0.933	-1.42	0.04
Cocoa	-0.345	-0.46	0.03
OJ	-3.347	-1.73	0.06
Lumber	-11.839	-2.52	0.08
Coffee	-0.029	-0.08	0.05
Grains group	-0.773	-1.43	
Wheat	-1.850	-1.47	0.03
Corn	0.444	0.37	0.02
Soybeans	-0.333	-0.29	0.02
Soybean Oil	-1.474	-0.79	0.02
Soybean Meal	-0.687	-0.43	0.02
Oats	-0.751	-0.86	0.01
Meats group	-2.819	-2.22	
Pork Bellies	-2.256	-1.98	0.05
Live Cattle	-2.131	-1.20	0.01
Lean Hogs	-4.262	-2.13	0.05
Feeder Cattle	-3.172	-1.84	0.03
Milk	-11.810	-1.57	0.09
Butter	-3.290	-1.19	0.06
Energies group	-8.706	-1.75	
Heating Oil	-6.608	-1.65	0.08
Crude Oil	-7.152	-0.60	0.06
Gasoline	-4.005	-0.24	0.09
Propane	-10.921	-1.78	0.09
Natural Gas	-10.215	-1.17	0.04
Coal	-8.052	-0.52	0.25

Table 5: Returns and Characteristics of Portfolios Sorted on the Inventories

At the end of each month the available commodities are ranked from high to low using normalized inventories, defined as ratio of the actual level of inventories (I) divided by the normal level of inventories (I*). The top half of the commodities are assigned to the High inventory portfolio and the bottom half to the Low inventory portfolio. Panel A of the table summarizes the annualized return distributions of the High and Low portfolios in excess of the equally-weighted (EW) index. Average returns and standard deviations are expressed as percent per annum. The bottom panel summarizes information about the average characteristics of the commodities in the High and Low portfolios, as well as the Positions of Traders as defined by the CFTC. Characteristics include: the 12-month futures return prior to portfolio formation, the 12-month prior % change in spot price prior to portfolio formation, the percentage basis, and the normalized inventories expressed as percentage difference between actual inventory level (I) and normal inventory level (I*) (defined as 100 times log(I/I*)), and volatility defined as the % standard deviation of the daily commodity futures returns during the month for which the excess return is calculated. Positions of Traders are measures as a percent of Open Interest at the time of sorting. The columns measure the characteristics of the commodities in the High portfolio, the Low portfolio, and the *t*-statistic for the difference.

Panel A: Returns Relative to EW Index

	1969/12-2006/12			1986/1-2006/12			1990/12-2006/12		
	High	Low	H-L	High	Low	H-L	High	Low	H-L
Mean	-3.85	4.21	-8.06	-3.64	3.61	-7.25	-4.38	4.37	-8.75
Standard Deviation	7.77	7.80	15.48	7.03	7.04	14.02	6.44	6.47	12.84
t -statistic (mean)	-3.03	3.32	-3.19	-2.34	2.33	-2.34	-2.83	2.80	-2.82
% Excess Return>0	42.57	56.53	43.47	41.04	57.37	42.23	41.67	57.29	43.23

Panel B: Average Portfolio Characteristics

	1969/12-2006/12			1986/1-2006/12			1990/12-2006/12		
	High	Low	*t* -stat	High	Low	*t* -stat	High	Low	*t* -stat
Prior 12m futures return	0.41	15.31	-6.45	1.24	12.97	-5.54	0.05	11.20	-5.43
Prior 12m spot return	6.00	9.78	-2.58	5.00	8.85	-2.39	5.33	8.59	-1.95
Basis	-7.78	4.61	-14.51	-6.86	4.51	-11.40	-8.81	2.79	-13.14
Inventories	36.37	-36.15		37.20	-35.19		40.80	-31.07	
Volatility (+1)	23.40	23.86	-1.15	23.75	23.90	-0.27	23.84	23.46	0.66
Commercials				-11.71	-7.97	-5.03	-12.33	-8.00	-4.81
Non-Commercials				5.59	5.28	0.58	6.01	5.66	0.53
Non Reportable				6.08	2.75	5.29	6.27	2.41	5.23

Table 6: Returns and Characteristics of Portfolios Sorted on the Futures Basis

At the end of each month the available commodities are ranked from high to low using the futures basis, defined as the annualized percentage difference between the nearest and next futures price. The top half of the commodities are assigned to the High Basis portfolio and the bottom half to the Low Basis portfolio. Panel A of the table summarizes the annualized return distributions of the High and Low portfolios in excess of the equally-weighted (EW) index. Average returns and standard deviations are expressed as percent per annum. The bottom panel summarizes information about the average characteristics of the commodities in the High and Low portfolios, as well as the Positions of Traders as defined by the CFTC. Characteristics include: the 12-month futures return prior to portfolio formation, the 12-month prior % change in spot price prior to portfolio formation, the percentage basis, and the normalized inventories expressed as percentage difference between actual inventory level (I) and normal inventory level (I*) (defined as 100 times log(I/I*)), and volatility defined as the % standard deviation of the daily commodity futures returns during the month for which the excess return is calculated. Positions of Traders are measures as a percent of Open Interest at the time of sorting. The columns measure the characteristics of the commodities in the High portfolio, the Low portfolio, and the *t*-statistic for the difference.

	1969/12-2006/12			1986/1-2006/12			1990/12-2006/12		
				Panel A: Returns Relative to EW Index					
	High	Low	H-L	High	Low	H-L	High	Low	H-L
Mean	5.42	-4.82	10.23	5.04	-4.70	9.74	5.71	-5.86	11.57
Standard Deviation	7.76	7.93	15.58	6.87	7.13	13.93	6.08	6.08	12.10
t -statistic (mean)	3.98	-3.44	3.73	3.55	-3.14	3.36	4.04	-4.10	4.08
% Excess Return>0	58.56	42.79	57.88	61.35	39.04	61.35	63.02	37.50	63.02
				Panel B: Average Portfolio Characteristics					
	High	Low	*t* -stat	High	Low	*t* -stat	High	Low	*t* -stat
Prior 12m futures return	21.02	-5.11	12.93	19.68	-5.40	12.99	17.50	-5.93	10.56
Prior 12m spot return	15.61	0.29	10.45	14.39	-0.51	9.51	14.11	0.00	7.16
Basis	15.32	-18.40		15.44	-17.73		13.04	-19.01	
Inventories	-14.87	15.31	-17.08	-13.78	15.95	-13.65	-9.34	19.09	-13.76
Volatility (+1)	24.07	23.23	2.13	24.30	23.31	1.72	23.98	23.30	0.99
Commercials				-8.94	-10.34	1.46	-9.87	-10.01	0.13
Non-Commercials				6.89	3.95	4.24	7.78	3.92	4.81
Non Reportable				2.38	6.12	-7.00	2.52	5.73	-5.99

Table 7: Returns and Characteristics of Portfolios Sorted on the Prior 12-month Futures Return

At the end of each month the available commodities are ranked from high to low using prior 12-month futures return. The top half of the commodities are assigned to the High momentum portfolio and the bottom half to the Low Momentum portfolio. Panel A of the table summarizes the annualized return distributions of the High and Low portfolios in excess of the equally-weighted (EW) index. Average returns and standard deviations are expressed as percent per annum. The bottom panel summarizes information about the average characteristics of the commodities in the High and Low portfolios, as well as the Positions of Traders as defined by the CFTC. Characteristics include: the 12-month futures return prior to portfolio formation, the 12-month prior % change in spot price prior to portfolio formation, the percentage basis, and the normalized inventories expressed as percentage difference between actual inventory level (I) and normal inventory level (I*) (defined as 100 times log(I/I*)), and volatility defined as the % standard deviation of the daily commodity futures returns during the month for which the excess return is calculated. Positions of Traders are measures as a percent of Open Interest at the time of sorting. The columns measure the characteristics of the commodities in the High portfolio, the Low portfolio, and the *t*-statistic for the difference.

	1969/12-2006/12			1986/1-2006/12			1990/12-2006/12		
Panel A: Returns Relative to EW Index									
	High	Low	H-L	High	Low	H-L	High	Low	H-L
Mean	6.54	-6.82	13.36	6.81	-7.03	13.84	7.69	-7.67	15.36
Standard Deviation	8.52	8.62	16.99	7.80	7.90	15.53	6.84	6.83	13.64
t -statistic (mean)	4.82	-4.95	4.93	4.24	-4.35	4.34	4.56	-4.62	4.60
% Excess Return>0	58.78	42.34	58.11	61.35	39.44	60.96	64.58	35.42	64.58
Panel B: Average Portfolio Characteristics									
	High	Low	*t* -stat	High	Low	*t* -stat	High	Low	*t* -stat
Prior 12m futures return	32.62	-16.65		31.57	-17.14		29.40	-17.79	
Prior 12m spot return	26.22	-10.43	23.52	25.54	-11.70	24.16	25.37	-11.23	20.33
Basis	6.73	-9.96	19.15	6.94	-9.30	17.97	5.03	-11.08	14.73
Inventories	-9.30	9.88	-8.26	-7.29	9.44	-6.07	-3.51	13.29	-5.74
Volatility (+1)	24.10	23.28	1.71	24.43	23.24	1.83	24.37	22.97	1.83
Commercials				-11.57	-8.01	-2.73	-12.53	-7.46	-3.61
Non-Commercials				9.02	1.58	9.81	10.11	1.24	11.72
Non Reportable				2.74	6.18	-4.31	2.67	5.89	-3.67

Table 8: Returns and Characteristics of Portfolios Sorted on the Prior 12-month Spot Return

At the end of each month the available commodities are ranked from high to low using prior 12-month spot return, defined as the percentage change in the spot price. The top half of the commodities are assigned to the High momentum portfolio and the bottom half to the Low Momentum portfolio. Panel A of the table summarizes the annualized return distributions of the High and Low portfolios in excess of the equally-weighted (EW) index. Average returns and standard deviations are expressed as percent per annum. The bottom panel summarizes information about the average characteristics of the commodities in the High and Low portfolios, as well as the Positions of Traders as defined by the CFTC. Characteristics include: the 12-month futures return prior to portfolio formation, the 12-month prior % change in spot price prior to portfolio formation, the percentage basis, and the normalized inventories expressed as percentage difference between actual inventory level (I) and normal inventory level (I*) (defined as 100 times log(I/I*)), and volatility defined as the % standard deviation of the daily commodity futures returns during the month for which the excess return is calculated. Positions of Traders are measures as a percent of Open Interest at the time of sorting. The columns measure the characteristics of the commodities in the High portfolio, the Low portfolio, and the *t*-statistic for the difference.

	1969/12-2006/12			1986/1-2006/12			1990/12-2006/12		
Panel A: Returns Relative to EW Index									
	High	Low	H-L	High	Low	H-L	High	Low	H-L
Mean	6.73	-7.12	13.85	8.55	-8.82	17.37	7.87	-8.16	16.03
Standard Deviation	8.69	8.58	17.19	8.53	8.34	16.83	6.71	6.78	13.44
t -statistic (mean)	4.77	-5.09	4.95	4.79	-5.07	4.94	4.36	-4.55	4.47
% Excess Return>0	56.76	41.67	57.88	59.76	38.25	60.96	61.46	36.98	61.98
Panel B: Average Portfolio Characteristics									
	High	Low	*t* -stat	High	Low	*t* -stat	High	Low	*t* -stat
Prior 12m futures return	28.61	-12.79	18.13	27.98	-13.58	22.84	25.99	-14.41	20.56
Prior 12m spot return	29.78	-13.87		28.60	-14.67		28.15	-14.01	
Basis	3.94	-7.08	11.57	4.71	-7.05	12.40	3.00	-9.00	10.22
Inventories	-3.00	3.27	-2.77	-2.25	4.09	-2.51	1.56	8.17	-2.57
Volatility (+1)	24.18	23.25	1.82	24.35	23.33	1.40	24.43	22.90	1.91
Commercials				-13.02	-6.45	-6.29	-14.03	-5.83	-7.80
Non-Commercials				9.60	1.14	13.68	10.59	0.95	16.12
Non Reportable				3.68	5.04	-1.87	3.78	4.53	-0.93

Table 9: Summary of Positions of Traders 1986 – 2006

The table summarizes the Positions of Traders in commodity futures markets according to the classifications employed in the Commitment of Traders Report published by the CFTC: For each category (Commercials, Non-Commercials, and Non-Reportables) positions are measured as net long and expressed as a percentage of Open Interest. The columns report the sample average position, the standard deviation of the position, the fraction of the months the position is long, and the first-order autocorrelation (rho) of the position.

		Net Long Positions of Traders as Percent of Open Interest											
		Commercials				Non-Commercials				Non Reportable			
	Commodity	Average	Stdev	%Long	rho	Average	Stdev	%Long	rho	Average	Stdev	%Long	rho
Metals	Copper	-16.67	22.70	26.19	0.76	8.28	17.01	67.86	0.74	8.39	8.42	85.32	0.81
	Platinum	-38.93	24.02	7.14	0.71	23.99	22.00	83.73	0.74	14.94	7.83	97.62	0.79
	Palladium	-30.48	30.15	22.62	0.92	17.33	18.70	76.59	0.88	13.15	14.72	82.14	0.92
Softs	Cotton	-4.02	23.11	42.06	0.71	-1.41	19.93	49.60	0.73	5.42	6.32	83.73	0.76
	Cocoa	-8.77	16.14	28.97	0.78	2.40	12.61	56.35	0.74	6.38	5.74	89.29	0.88
	Sugar	-20.72	21.66	22.62	0.73	9.43	14.85	72.22	0.72	11.30	9.04	90.08	0.77
	Orange Juice	-15.06	25.57	26.19	0.77	6.38	17.41	64.29	0.70	8.68	13.65	83.73	0.86
	Lumber	-10.50	18.62	32.14	0.74	4.57	15.21	66.67	0.62	5.93	12.00	69.84	0.74
	Coffee	-17.41	15.38	16.67	0.59	6.49	13.65	69.84	0.56	10.92	4.76	100.00	0.76
Grains	Wheat	-9.35	15.77	30.95	0.73	4.60	12.74	59.52	0.73	4.75	8.54	68.25	0.80
	Corn	1.01	13.81	51.59	0.76	5.69	10.97	66.27	0.74	-6.70	5.97	11.11	0.83
	Soybeans	-10.73	17.61	27.38	0.87	6.67	12.68	70.24	0.80	4.06	7.68	68.65	0.89
	Soybean Oil	-13.11	18.28	28.97	0.74	5.17	12.94	63.49	0.75	7.94	7.23	87.70	0.72
	Soybean Meal	-13.72	14.89	21.43	0.70	4.67	10.25	67.06	0.70	9.04	5.85	94.05	0.69
	Oats	-37.15	15.92	1.19	0.71	11.95	11.51	90.87	0.77	25.20	13.49	98.02	0.82
	Rough Rice	-7.43	21.14	37.07	0.85	2.72	13.35	53.88	0.83	4.71	13.99	56.90	0.82
Meats	Pork Bellies	-0.84	14.41	43.65	0.76	-1.91	18.82	44.84	0.68	2.75	18.76	53.17	0.80
	Live Cattle	-8.31	11.34	26.98	0.85	8.05	10.25	75.40	0.73	0.26	10.21	48.02	0.88
	Lean Hogs	0.59	12.02	46.83	0.68	5.81	14.47	66.67	0.64	-6.40	7.99	17.46	0.56
	Feeder Cattle	8.79	11.90	75.00	0.75	8.86	12.96	76.19	0.70	-17.65	13.99	14.29	0.87
	Milk	10.94	16.42	76.58	0.85	1.12	10.89	45.05	0.75	-12.06	8.83	4.50	0.75
Energies	Heating Oil	-9.00	9.75	18.65	0.61	1.80	6.26	59.92	0.55	7.20	5.41	90.87	0.72
	Crude Oil	-0.10	8.43	47.62	0.66	0.39	6.28	50.79	0.68	-0.29	3.39	46.83	0.58
	Unleaded Gas	-8.76	11.43	23.81	0.60	6.54	8.58	76.19	0.65	2.22	4.50	73.02	0.38
	Propane	-9.82	11.83	19.74	0.71	-0.61	6.08	28.29	0.71	10.43	10.35	82.24	0.65
	Natural Gas	-7.01	8.22	22.00	0.63	0.76	7.21	56.00	0.65	6.25	3.47	98.00	0.79

Table 10: Hedging Pressure and Futures Returns 1986/12 – 2006/12

The table summarizes the results of a simple regression of futures returns realized at the end of month *t* on Commercial Positions measured at time *t* (contemporaneous) and measured at the end of month *t-1* (lagged). Commercial Positions are defined as the net long position in a commodity future expressed as a percent of the Open Interest in that commodity using data obtained from the Report of Traders of the CFTC. The independent variable is measured in levels (left panel) and in first differences (right panel). The table reports the slope coefficient and the associated *t*-statistic, and the R-squared of the regression.

Independent Variable		Commercial Positions (Levels)						Commercial Positions (First Differences)					
		Contemporaneous			Lagged			Contemporaneous			Lagged		
	Commodity	slope	*t* -stat	R-sq	slope	*t* -stat	R-sq	slope	*t* -stat	R-sq	slope	*t* -stat	R-sq
Metals	Copper	-0.13	-4.95	0.13	-0.02	-0.91	0.00	-0.24	-8.22	0.20	-0.02	-0.58	0.00
	Platinum	-0.10	-7.49	0.16	0.00	-0.03	0.00	-0.16	-9.60	0.27	0.02	0.99	0.00
	Palladium	-0.06	-2.54	0.04	-0.03	-1.22	0.01	-0.18	-4.09	0.06	-0.06	-1.36	0.01
Softs	Cotton	-0.16	-8.82	0.22	-0.02	-1.15	0.01	-0.23	-9.85	0.28	0.00	0.04	0.00
	Cocoa	-0.15	-4.50	0.09	0.00	0.13	0.00	-0.34	-7.99	0.20	0.02	0.48	0.00
	Sugar	-0.19	-7.24	0.18	0.00	-0.08	0.00	-0.34	-10.90	0.33	-0.02	-0.62	0.00
	Orange Juice	-0.07	-3.35	0.05	-0.02	-0.76	0.00	-0.13	-4.55	0.07	0.04	1.32	0.01
	Lumber	-0.11	-3.70	0.05	-0.03	-0.97	0.00	-0.15	-3.70	0.05	0.03	0.79	0.00
	Coffee	-0.31	-6.85	0.17	0.04	0.86	0.00	-0.42	-9.91	0.26	0.10	1.96	0.01
Grains	Wheat	-0.15	-6.12	0.15	0.01	0.49	0.00	-0.31	-10.68	0.31	0.02	0.68	0.00
	Corn	-0.23	-8.32	0.21	-0.01	-0.30	0.00	-0.46	-13.09	0.40	0.00	-0.03	0.00
	Soybeans	-0.10	-5.19	0.08	0.01	0.27	0.00	-0.41	-11.64	0.36	-0.02	-0.42	0.00
	Soybean Oil	-0.16	-8.31	0.18	0.00	0.13	0.00	-0.31	-11.57	0.35	0.02	0.52	0.00
	Soybean Meal	-0.20	-7.40	0.17	0.00	-0.04	0.00	-0.33	-10.11	0.29	0.01	0.13	0.00
	Oats	-0.01	-0.23	0.00	0.09	2.17	0.02	-0.17	-3.21	0.04	0.01	0.13	0.00
	Rough Rice	-0.09	-3.49	0.05	-0.06	-2.43	0.02	-0.09	-2.07	0.02	-0.04	-0.78	0.00
Meats	Pork Bellies	0.02	0.35	0.00	0.04	0.79	0.00	-0.05	-0.61	0.00	0.06	0.85	0.00
	Live Cattle	-0.09	-4.22	0.06	-0.03	-1.38	0.01	-0.19	-4.75	0.08	0.00	-0.06	0.00
	Lean Hogs	-0.19	-5.63	0.09	0.01	0.22	0.00	-0.30	-6.46	0.15	0.06	1.16	0.01
	Feeder Cattle	-0.03	-1.23	0.01	0.05	2.39	0.02	-0.16	-5.72	0.12	-0.02	-0.80	0.00
	Milk	-0.14	-2.41	0.08	-0.08	-1.23	0.02	-0.25	-2.57	0.06	-0.13	-1.30	0.02
Energies	Heating Oil	-0.46	-8.22	0.22	-0.05	-0.75	0.00	-0.51	-8.39	0.22	-0.07	-0.97	0.00
	Crude Oil	-0.49	-6.73	0.17	-0.12	-1.60	0.01	-0.51	-6.34	0.13	-0.07	-0.83	0.00
	Unleaded Gas	-0.35	-6.70	0.15	-0.05	-0.95	0.00	-0.36	-6.05	0.13	-0.10	-1.56	0.01
	Propane	0.10	1.03	0.01	-0.12	-1.22	0.01	0.38	2.88	0.05	-0.23	-1.69	0.02
	Natural Gas	-0.77	-6.13	0.17	-0.10	-0.71	0.00	-0.90	-6.40	0.17	-0.14	-0.88	0.00

Figure 1: Excess Returns and Basis

The figure plots the sample average basis against the sample average futures excess return for individual commodity futures between 1990/12 and 2006/12. The basis is measured as the relative price difference between the two closest to maturity contracts, expressed as a percent per annum

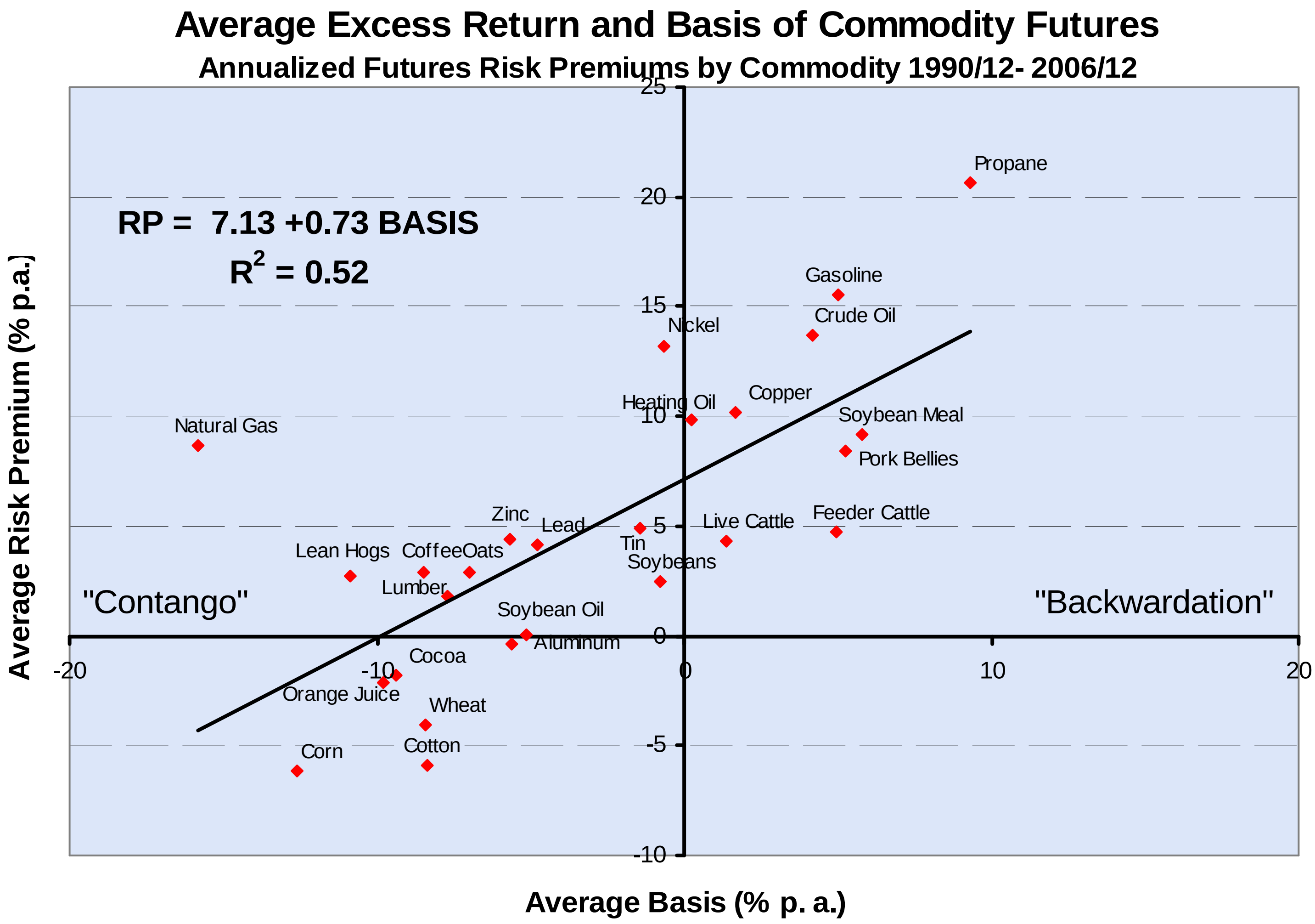
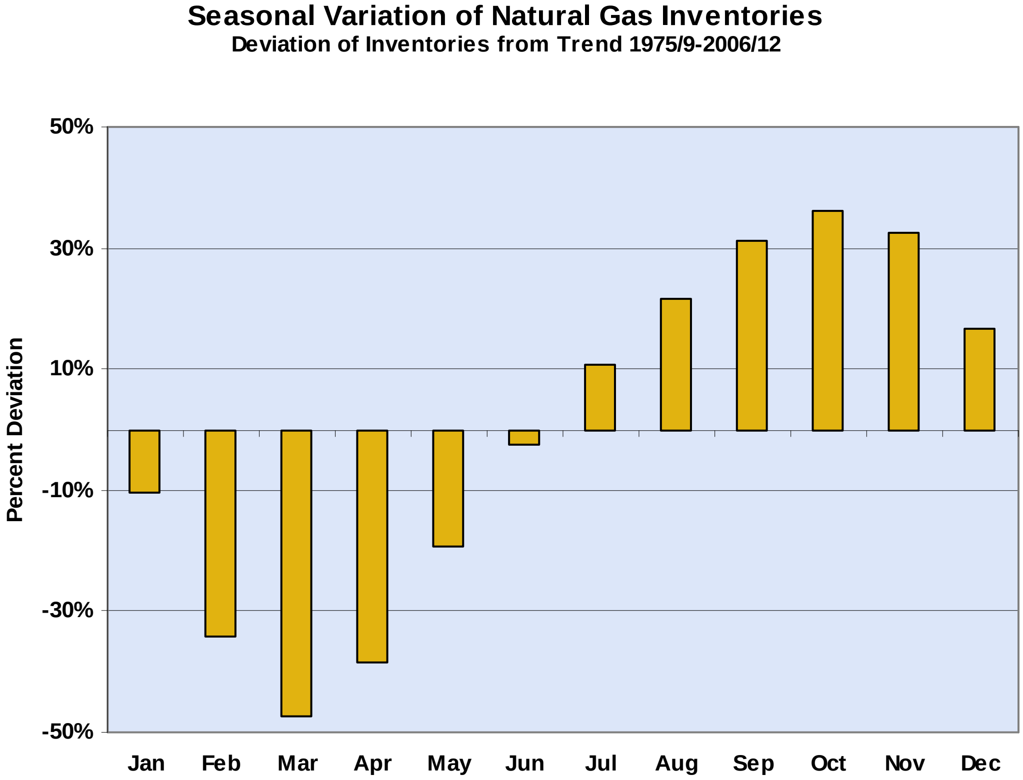
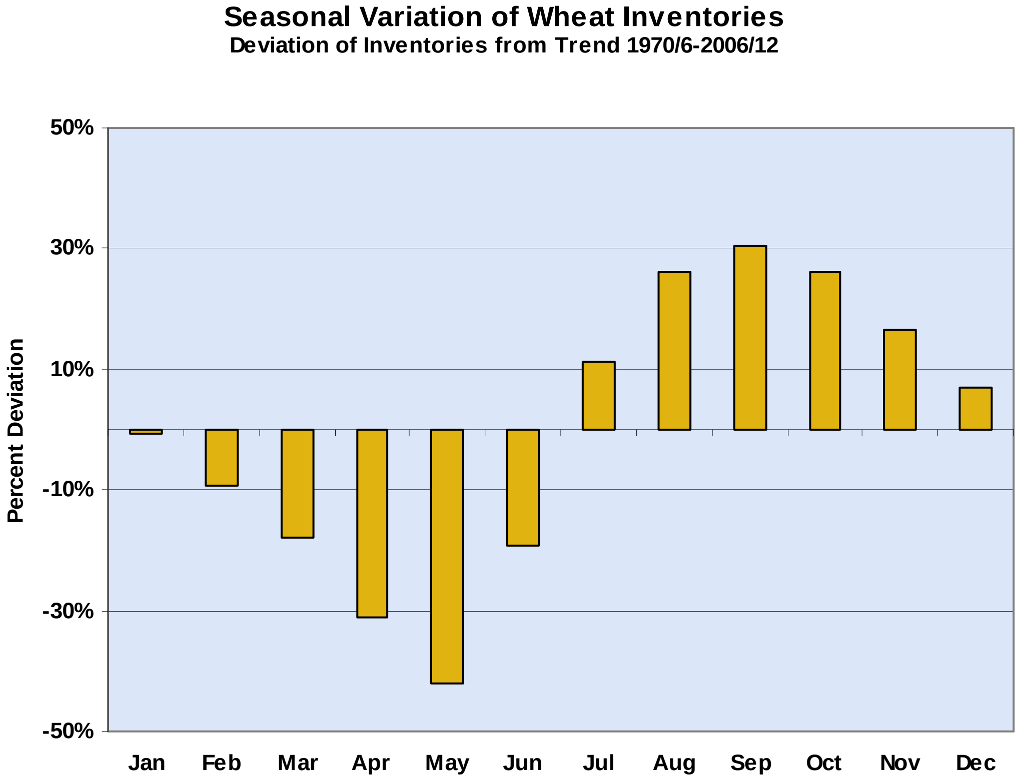
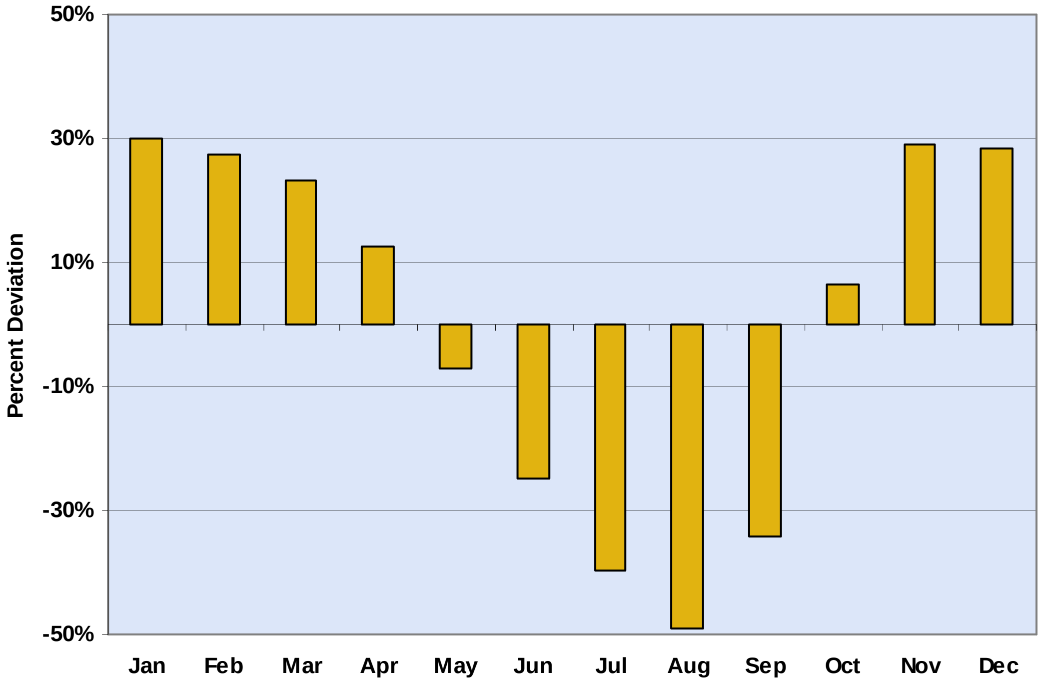


Figure 2: Seasonal Variation of Inventories

The figure graphs the fitted coefficients of a regression of log of inventories, measured in deviation from HP filtered inventories, on monthly dummies. Panel A plots the seasonal coefficients for Natural Gas Inventories, and Panel B shows the seasonal variation for inventories of Corn.







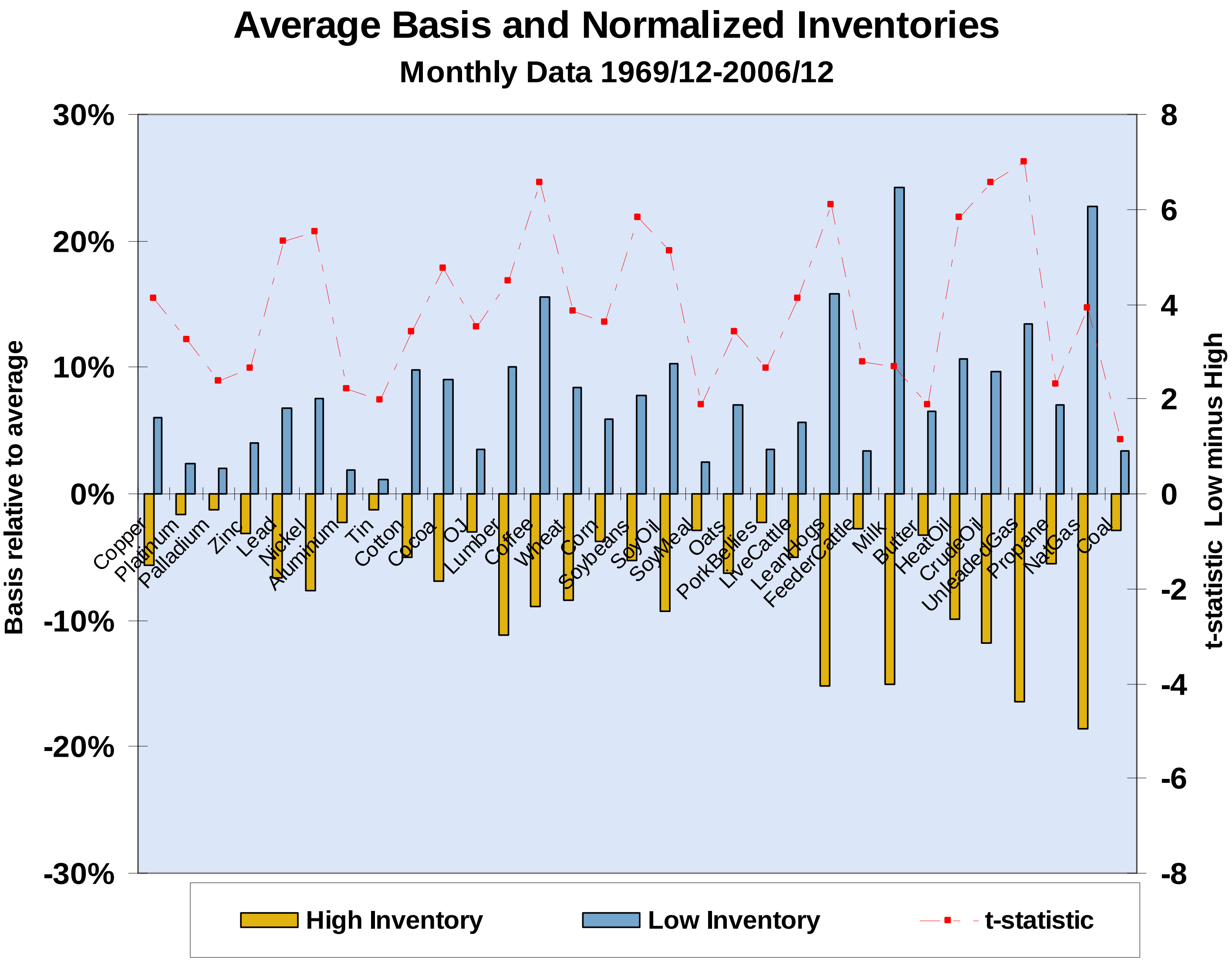
Seasonal Variation of Corn Inventories

Deviation of Inventories from Trend 1974/6-2006/12

Figure 3: Normalized Inventories and Characteristics

For each commodity we divide the sample in months when actual relative to normalized inventories is above unity (High) and when it is below unity (Low). In Panel A, we plot for each commodity the average basis in High and Low inventory months, expressed in deviation from the full sample mean. In Panel B, we show for each commodity the prior 12-month futures returns in High and Low inventory months, expressed in deviation from the annualized sample average 12-m return. The t-statistics of a test for the difference of +the characteristics is given in red.

Panel A



Panel B

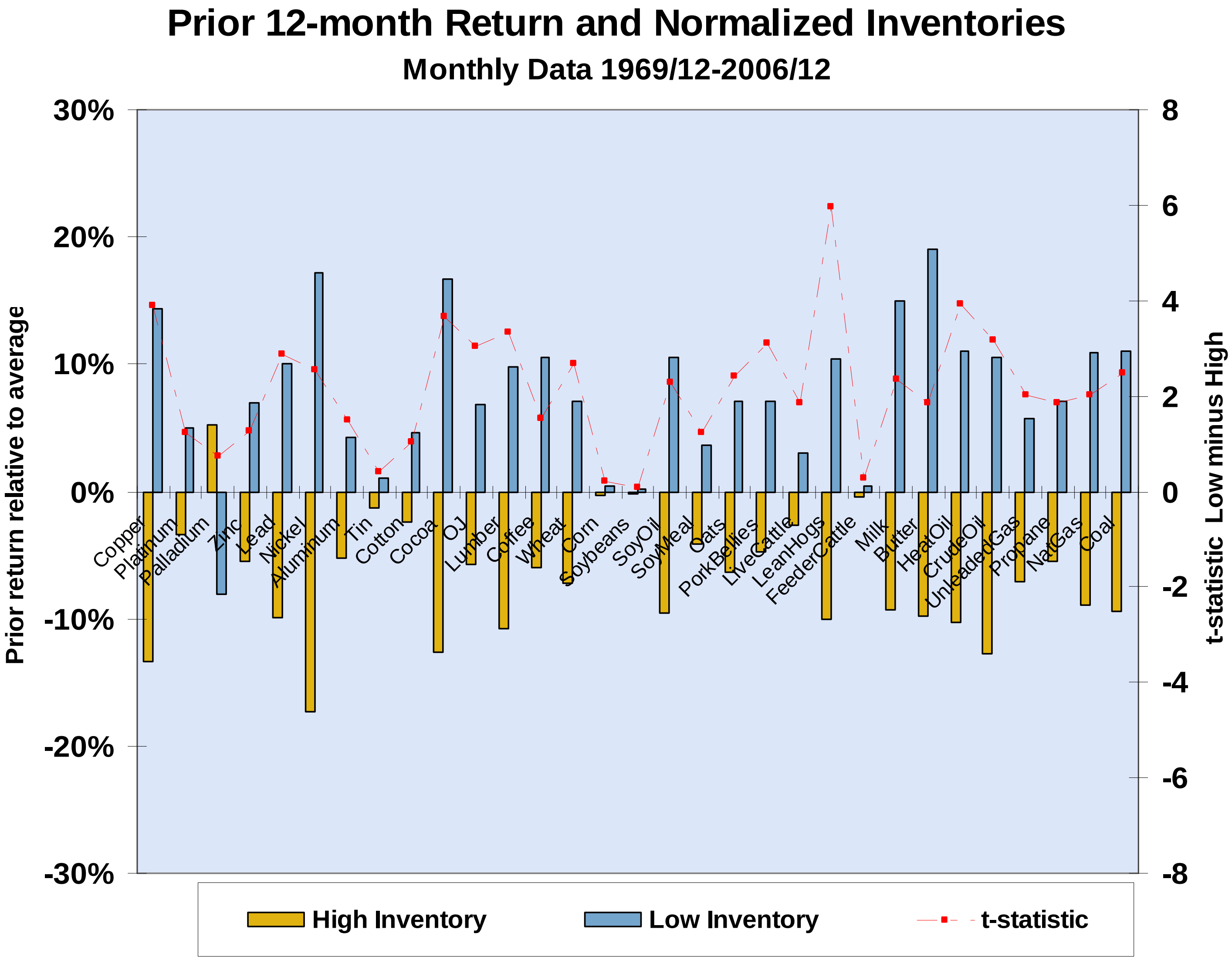

Prior 12-month Return and Normalized Inventories
Monthly Data 1969/12-2006/12
Prior return relative to average
t-statistic Low minus High
30%
20%
10%
0%
-10%
-20%
-30%
8
6
4
2
0
-2
-4
-6
-8
Copper
Platinum
Palladium
Zinc
Lead
Nickel
Aluminum
Tin
Cotton
Cocoa
OJ
Lumber
Coffee
Wheat
Corn
Soybeans
SoyOil
SoyMeal
Oats
PorkBellies
LiveCattle
LeanHogs
FeederCattle
Milk
Butter
HeatOil
CrudeOil
UnleadedGas
Propane
NatGas
Coal
High Inventory
Low Inventory
t-statistic

Figure 4: Basis and Normalized Inventories

The figure shows a scatter plot of the monthly observations of the futures basis against the ratio of inventories relative to trend (I/I*) for Copper and Crude Oil. The basis is net of seasonal effect, i.e., after subtracting the estimated linear function of monthly dummies in the cubic spline regression. In addition (in red) we give the fitted values of a cubic spline regression of the basis on inventories.