Review of Finance Advance Access published August 9, 2012

Review of Finance (2012) pp. 1–71
doi:10.1093/rof/rfs019

The Fundamentals of Commodity Futures Returns

GARY B. GORTON[1,2], FUMIO HAYASHI[2,3] and
K. GEERT ROUWENHORST[1,*]
[1]*School of Management, Yale University,* [2]*National Bureau of Economic Research, and* [3]*Graduate School of International Corporate Strategy, Hitotsubashi University*

Abstract. Commodity futures risk premiums vary across commodities and over time depending on the level of physical inventories. The convenience yield is a decreasing, nonlinear function of inventories. Price measures, such as the futures basis, prior futures returns, prior spot returns, and spot price volatilities reflect the state of inventories and are informative about commodity futures risk premiums. We verify these theoretical predictions using a comprehensive data set on 31 commodity futures and physical inventories between 1971 and 2010. We find no evidence that the positions of participants in futures markets predict risk premiums on commodity futures.

JEL Classification: G12, G13

1. Introduction

Using a large cross-section of commodity futures and associated inventory data, we analyze the fundamentals of commodity futures excess returns (the future spot price at maturity minus its current futures price). We show that time-series variation and cross-sectional variation in the *risk premium* (the expected or ex ante excess return) are determined by the level of inventories of the commodity. We also show how price-based signals such as the *basis* (the difference between the current spot price and the contemporaneous

* The article has benefited from comments by seminar participants at McGill University, Yale University, University of Maryland, the Wharton School Weiss Center Conference on Alternative Investments, the Q-Group, AQR, the Board of Governors of the Federal Reserve System, the University of British Columbia, American University, University of North Carolina, Universidad Carlos III Madrid, ISCTE – IUL Conference Lisbon, the Ceasarea Center, and from Kobi Boudoukh, Steve Heston, David Hirshleifer, Scott Irwin, Pete Kyle, Toby Moskowitz, and Robert Pindyck. We thank Geetesh Bhardwaj, Dimitry Gupalo, and Sebastian Heise for research assistance, and AIG Financial Products and the Q-Group for financial support.

futures price), prior futures returns and past spot returns, and spot price volatility are empirically related to inventory levels and the risk premium.

Existing theories of commodity futures imply that the inventory level of the physical commodity is the fundamental determinant of the risk premium and the basis. The theoretical literature on commodity futures can be viewed as consisting of two strands, each focusing on different aspects of futures markets. First, the traditional Theory of Storage (see Kaldor, 1939; Working, 1949; Brennan, 1958) assumes that holders of inventories receive implicit benefits, called the "convenience yield", that decline as inventory increases. Since it accrues to owners of inventories but not to owners of futures contracts, the convenience yield is closely tied to the basis (see Equation (1) below). Second, the Theory of Normal Backwardation of Keynes (1930) and Hicks (1939) assumes that commodity producers and inventory holders hedge future spot price risk by taking short positions in the futures market. To induce risk-averse speculators into taking the opposite long positions, current futures prices are set at a discount (i.e., is "backwardated") to expected future spot prices at maturity. The commodity futures risk premium is the size of this discount.

To our knowledge there has been no published paper featuring an optimization-based model that derives both the basis and the risk premium endogenously. To fill this void, we will present a simple two-period model that integrates the Theory of Storage and the Theory of Normal Backwardation and show how the basis and the risk premium are related to inventories. In our model, when initial inventory levels are high enough to allow inventory holders to move the commodity from the present to the future, the convenience yield is zero and the basis is determined by the cost of storage. Otherwise, in the event of a *stock-out*, the convenience yield is positive to reflect a spot price increase due to a shortage of goods. Therefore, as assumed in the Theory of Storage, the convenience yield, and hence the basis, are declining and convex functions of inventories. Although the effect of inventories on the risk premium is ambiguous in our model, we show that if the spot demand is not too inelastic so that the volatility of future spot prices falls fast enough with an increase in inventories, the risk premium declines with inventories.

The main contribution of our article is an empirical examination of the effect of inventories on the basis and the risk premium articulated by the theory just outlined. We do so by using a comprehensive data set on 31 commodity futures and physical inventories between 1971 and 2010. We find that for many commodities, the futures basis exhibits precisely the sort of nonlinearities predicted by the theory. We present two tests of whether the risk premium is negatively related to inventories. The first test regresses the excess return (whose expected value is the risk premium) on lagged inventory levels. Secondly, we show that sorting commodity futures into portfolios using inventories as a signal significantly spreads the portfolio returns, with low-inventory portfolios earning higher returns.

Our model predicts that price-based signals—such as the basis, prior futures excess returns, prior spot price changes, and spot price volatility—are related to inventories. We show empirically that investment strategies based on those price-based signals are also correlated with the risk premium. For example, a portfolio that selects commodities with a relatively high basis or high past returns significantly outperforms a portfolio of low basis or low past return commodities. Inspection of the inventory characteristics of the commodities when selected shows that the returns earned on these "backwardation" and "momentum" strategies can be interpreted as compensation for bearing risk during times when inventories are low.

Finally, we characterize the behavior of market participants in futures markets in response to inventories. This is of interest because in empirical implementations of the Theory of Normal Backwardation researchers have linked "hedging pressure", measured by the relative size of positions held by producers, to the risk premium.[1] We show that the positions of traders are contemporaneously correlated with inventories and futures prices. However, we find no evidence that these positions are correlated with subsequent commodity futures returns.

The remainder of the article is organized as follows. In Section 2 we provide a brief literature survey and develop a simple model of the basis and the risk premium. Section 3 documents our data and some stylized facts. Section 4 presents the regression-based evidence of the effect of inventories on the basis and the risk premium followed by the portfolio sorting results from selecting commodity futures by inventory levels. In Section 5 we analyze the returns to price-based commodity selection strategies. In Section 6 we characterize the relation between the trading behavior of futures markets participants and the risk premium. The final section of the article summarizes our results and suggests some possible avenues for future research.

[1] See, e.g., Carter, Rausser, and Schmitz (1983); Chang (1985); Bessembinder (1992); De Roon, Nijman, and Veld (2000); Dincerler, Khokher, and Simin (2005); Khan et al. (2008).

2. Literature Review and the Model

In this section, we provide a brief survey of the literature on commodity futures and present a simple two-period model that illustrates the points made in the literature survey. The literature survey covers only those papers that derive spot and futures prices endogenously; the continuous-time literature starting from Brennan and Schwartz (1985) and Schwartz (1997), which requires an exogenous specification of the spot price and the convenience yield, is outside the scope of the literature survey.

2.1 A BRIEF LITERATURE SURVEY

The central assumption of the traditional Theory of Storage is that the convenience yield, denoted c_t for date t, is a function of the inventory level and falls at a decreasing rate as inventory rises. The convenience yield is defined by the well-known no-arbitrage condition. That is, let S_t be the spot price at date t and let $F_{t,T}$ be the futures price (as of date t) for delivery at date T. The *basis* at date t is defined as $S_t - F_{t,T}$. The negative of the basis consists of: interest foregone by holding the commodity, $S_t r_t$ (where r_t is the interest charge on a dollar from t to T), plus the unit storage cost, w_t, minus the convenience yield from an additional unit of inventory, c_t:

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

This equation allows us to measure the convenience yield as the interest-adjusted basis $(1 + r_t)S_t - F_{t,T}$ plus an estimate of the unit storage cost.

Empirical tests of the traditional Theory of Storage examine the theory's central assumption utilizing the convenience yield inferred from the (interest-adjusted) basis. Fama and French (1988) and Ng and Pirrong (1994), among others, derive testable implications of the assumption for the behavior of the spot and futures prices and their volatilities. Using futures data on metals, they find evidence in support of the theory. Their evidence is indirect because they do not use data on inventories. Brennan (1991) and Pindyck (1994) use inventory data to find that the convenience yield is indeed a decreasing and convex function of inventory for metals and some other commodities. More recent evidence can be found in Dincerler, Khokher, and Simin (2005) for gold, copper, crude oil, and natural gas, and Carbonez, Nguyen, and Sercu (2009) for wheat, corn, and oats using weekly data from two different periods, 1885–1935 and 1985–2005.

There is a modern, optimization-based version of the Theory of Storage that emanates from Deaton and Laroque (1992). Inventories act as buffer stocks that help to absorb shocks to demand and supply affecting spot prices. But inventories cannot be negative (goods cannot be transferred from the future to the past), so there is a possibility of a *stock-out* in which nonnegativity constraint on inventories binds. Deaton and Laroque (1992) show that at low inventory levels, the risk of a stock-out increases and future spot price volatility rises. They do not model futures markets, however.

Routledge, Seppi, and Spatt (2000) introduce a futures market into the model of Deaton and Laroque (1992). They show how the convenience yield arises endogenously as a function of the level of inventories and supply and demand shocks. Even if there is no direct benefit from owning physical inventories, the convenience yield can be positive because inventories have an option value due to a positive probability of a stock-out.[2] However, because agents are risk-neutral in the Deaton–Laroque (1992) and Routledge Seppi, and Spatt (2000) models, the commodity futures risk premium, which is viewed as an insurance premium in the Theory of Normal Backwardation of Keynes (1930) and Hicks (1939), is zero by assumption.

Modern formulations of the Theory of Normal Backwardation can be found in Stoll (1979) and Hirshleifer (1988, 1990). They make two basic assumptions. First, the revenue from the physical control of a commodity by hedgers is nonmarketable. This assumption might be justified if hedgers in the futures markets are either privately held firms or individual farmers. Second, participation in commodity futures markets by outside investors is limited by some (possibly informational) entry barriers, so a positive risk premium will not be competed away. As in the capital asset pricing model of Mayers (1972), the commodity futures risk premium consists of not only the systematic risk (i.e., the covariance with the market portfolio of traded assets) but also a component related to the volatility of spot prices.

Empirical studies since Dusak (1973) generally find the systematic risk of commodity futures to be close to zero and fail to reject a nonzero risk

[2] Probably the first formulation of the option value argument is Bresnahan and Spiller (1986) and Heinkel, Howe, and Hughes (1990). Litzenberger and Rabinowitz (1995) also link the basis to the option values of inventories. In their model of natural resource extraction, the producer chooses between producing (i.e., extracting from oil reserves) now or later. They show that the basis can be positive because current spot price must be sufficiently high relative to the current futures price in order to prevent producers from deferring extraction. More recently, Evans and Guthrie (2008) derive the convenience yield by assuming an adjustment cost in changing the inventory level.

premium for individual commodity futures (see, for example, Bessembinder, 1992; Kolb, 1992; Erb and Harvey, 2006). Looking at *portfolios* of commodity futures returns has produced different results. Bodie and Rosansky (1980) and Gorton and Rouwenhorst (2005, 2006) provide empirical evidence for a positive risk premium. Gorton and Rouwenhorst (2006) also report that the systematic risk component of the risk premium is small. This result is consistent with the market segmentation model of Stoll (1979) and Hirshleifer (1988, 1990) mentioned above and with Jagannathan's (1985) result that restrictions on the futures and market returns imposed by the CCAPM (consumption CAPM) can be rejected.[3]

Early work on the determinants of the risk premium by Fama and French (1987) finds that the risk premium is related to the basis and hence time-varying because the basis has a significant coefficient when the excess return (the expected value of which is the risk premium) is regressed on it. In a number of recent papers, the risk premium is found to be related to past realizations of the excess return (Pirrong, 2005; Erb and Harvey, 2006; Miffre and Rallis, 2007; Shen, Szakmary, and Sharma, 2007), macroeconomic predictors as well as the basis (Szymanowska *et al.,* 2011), open-interest growth (Hong and Yogo, 2012), and measures of the default risk of speculators (Etula, 2010) and of producers (Acharya, Lochstoer, and Ramadorai, 2010). The role of inventories is examined in several recent unpublished papers. Dincerler, Khokher, and Simin (2005) and Khan, Khokher, and Simin (2008) find that the excess return is significantly and positively related to both the *change* in inventory and a measure of "hedging pressure" for crude oil and natural gas but not for gold and copper.[4] Acharya, Lochstoer, and Ramadorai (2010), just cited above, has inventory as well as their measure of the default risk in the excess return regression for crude oil, heating oil, gasoline, and natural gas.

We draw two conclusions from this brief review of the literature. First, there exists no optimization-based equilibrium model that derives both the basis and the risk premium endogenously.[5] Second, we know of no

[3] However, a recent paper by Dhume (2010) reports that those restrictions cannot be rejected if the CCAPM is generalized to include durable consumption as in Yogo (2006).

[4] The results are different, however when level of inventories is studied. In that case, Dincerler, Khokher, and Simin (2005) report that the inventory coefficient is mostly insignificant and negative.

[5] The Hirshleifer (1988, 1990) model is about the risk premium, but he does not model inventories. Stoll (1979) and Turnovsky (1983) feature the risk premium, the basis, and inventories. However, Stoll's model treats the spot price as exogenous. Turnovsky's model assumes that commodity market participants can take short positions in the commodity. Thus in neither model can one address the role of stock-outs for the basis and the risk

systematic study covering a large cross-section of commodities that empirically examines the role of inventories for the basis and the risk premium.

2.2 A SIMPLE MODEL OF THE BASIS AND THE RISK PREMIUM

In order to organize ideas and hypotheses for our empirical work, we consider a simple two-period mean–variance model with hedgers (namely, producers) and speculators. It combines features emphasized by the Theory of Storage and the Theory of Normal Backwardation. For simplicity, the interest rate is assumed zero. There are two periods, 0 and 1. Speculators and hedgers trade in the spot market and the futures market in the first period (period 0). In the second period (period 1) there is a spot market, and futures contracts mature. For simplicity, both types of agents are assumed to have mean–variance preferences.

Consider first the decision problem of the hedgers. At the beginning of period 0, the representative hedger has on hand an amount I of the commodity. Let x be the amount of inventory to be carried over to the next period and thus required to be nonnegative. The hedger sells $I-x$ units in the spot market in period 0. The hedger's period 0 profit, Π_0, is:

$$\Pi_0 \equiv S(I-\bar{x}) \times (I-x), \tag{2}$$

where $S(.)$ is the inverse demand function assumed to be decreasing in its argument, and $\bar{x}$ is the average of x over the identical hedgers (in equilibrium, since each hedger acts in the same way, we will have $\bar{x}=x$). In period 0, the hedger also sells N units of futures contracts at a futures price F. The position taken is *long* if N is *negative*. The amount of goods for sale by the hedger in the spot market in the final period 1 is $\tilde{z}+(1-\delta)x-N$, where $\tilde{z}$ is the endowment for the hedger (a tilde over z emphasizes that the variable is random as of date 0) and δ is the depreciation rate (i.e., the unit storage cost). For the economy as a whole, the supply in period 1 equals $\tilde{z}+(1-\delta)\bar{x}$.

Let $\tilde{\varepsilon}$ be a demand shock in period 1. Then the spot price in period 1 is $S(\tilde{z}+(1-\delta)\bar{x}-\tilde{\varepsilon})$, and the representative hedger's period 1 profit is:

$$\Pi_1 \equiv S(\tilde{z}+(1-\delta)\bar{x}-\tilde{\varepsilon}) \times (\tilde{z}+(1-\delta)x-N)+FN \tag{3}$$

premium. Independently of our work, Acharya, Lochstoer, and Ramadorai (2010) have a simple model that is similar to ours, to be presented in the next subsection. Their model's focus is the relation between the risk premium and producers' risk tolerance.

The hedger's decision problem is:

$$\max_{x,N}\left\{\Pi_0 + E(\tilde{\Pi}_1) - \frac{\alpha}{2} Var(\tilde{\Pi}_1)\right\}\text{subject to } x \geq 0.$$

For notational brevity, let $\tilde{S}_1 \equiv S(\tilde{z} + (1-\delta)\bar{x} - \tilde{\varepsilon})$. We can rewrite the variance term in the objective function as:

$$Var(\tilde{\Pi}_1) = Var(\tilde{S}_1)[(1-\delta)x - N]^2 + Var(\tilde{S}_1\tilde{z}) + 2Cov(\tilde{S}_1\tilde{z}, \tilde{S}_1)[(1-\delta)x - N]. \tag{4}$$

The first term on the right-hand side captures the price uncertainty faced by the hedger. The remaining two terms come about because the hedger faces quantity risk as well as price risk.

Let $S_0 \equiv S(I - \bar{x})$ be the current spot price. Straightforward algebra shows that the first-order conditions (foc's) are:

$$(\text{w.r.t. } x) \quad \frac{S_0}{1-\delta} \geq E(\tilde{S}_1) - \alpha\left\{Var(\tilde{S}_1)[(1-\delta)x - N] + Cov(\tilde{S}_1\tilde{z}, \tilde{S}_1)\right\}, \quad \text{``}=\text{'' if } x > 0, \tag{5}$$

$$(\text{w.r.t. } N) \quad E(\tilde{S}_1) - F = \alpha\left\{Var(\tilde{S}_1)[(1-\delta)x - N] + Cov(\tilde{S}_1\tilde{z}, \tilde{S}_1)\right\}. \tag{6}$$

The foc (6) represents the risk premium $E(\tilde{S}_1) - F$. Adding the two foc's together, we obtain an expression for the basis:

$$\frac{S_0 - F}{F} \geq -\delta, \text{``}=\text{'' if } x > 0. \tag{7}$$

This last equation corresponds to condition (1) above. In the present model, the interest rate is zero and the nominal unit storage cost is δF, so in period 0, Equation (1) can be written as:

$$F - S_0 = \delta F - c_0 \text{ or } \frac{S_0 - F}{F} = -\delta + \frac{c_0}{F}. \tag{1'}$$

Equation (7) then implies that, consistent with the modern Theory of Storage, the convenience yield c_0 is nonnegative, and the basis as a fraction of the futures price is greater than the negative of δ (the unit storage cost) only when a stock-out occurs, i.e., when the nonnegativity constraint on x (the amount of inventory to be carried over to the next period) is binding.

Turning to the speculators, their wealth in period 1 is $\tilde{W} \equiv e_0 + (\tilde{S}_1 - F)N$, where e_0 is the speculator's initial endowment. The speculator's objective is to maximize

$$E(\tilde{W}) - \frac{\beta}{2}Var(\tilde{W}) = e_0 + \Big[E(\tilde{S}_1) - F\Big]N - \frac{\beta}{2}Var(\tilde{S}_1)N^2$$

over N. The foc is:

$$E(\tilde{S}_1) - F - \beta Var(\tilde{S}_1)N = 0 \text{ or } N = \frac{E(\tilde{S}_1) - F}{\beta Var(\tilde{S}_1)}. \tag{8}$$

An equilibrium is a triple (x, N, F) such that: (a) the hedger's first-order conditions Equation (6) about the risk premium and Equation (7) about the basis are satisfied; (b) the speculator's foc Equation (8) is satisfied; and (c) $\bar{x} = x$.[6] Denoting by b the basis as a fraction of the futures price (i.e., $b \equiv (S_0 - F)/\mathrm{F}$), we can easily reduce these equilibrium conditions into a system of two equations in two unknowns (b,x):

$$1 + b \geq 1 - \delta, \text{“} = \text{”} \text{ if } x > 0, \tag{9a}$$

$$1 + b = \frac{S(I - x)}{S_1^e(x) - \phi(x)}. \tag{9b}$$

Here, Equation (9a) merely restates the arbitrage condition (7). In Equation (9b), $S_1^e(x)$ is the expected next-period spot price when the amount of inventory carried over to the next period is x:

$$S_1^e(x) \equiv E[S(\tilde{z} + (1 - \delta)x - \tilde{\varepsilon})] = E(\tilde{S}_1) \tag{10}$$

and $\phi(x)$ is defined as:

$$\phi(x) \equiv \frac{\alpha\beta}{\alpha + \beta}\Big\{Var(\tilde{S}_1)(1 - \delta)x + Cov(\tilde{S}_1\tilde{z}, \tilde{S}_1)\Big\}. \tag{11}$$

The value of the function $\phi(x)$ is the risk premium $E(\tilde{S}_1) - F$, as one can see by eliminating N from Equations (6) and (8).[7] Equation (9b) states that the basis is a premium in the current spot price $S(I-x)$ over the risk-adjusted expected next-period spot price $S_1^e(x) - \phi(x)$.

[6] The equilibrium condition for the futures market is already embedded in the notation: The N for hedgers is also the N for speculators.

[7] This expression for the risk premium, (11), reduces to Hirshleifer's (1988) equation 9 (for the case of a fixed number of speculators) when we set $\alpha = \beta$ and ignore inventory by setting $x = 0$. His model is not a special case of ours because it allows hedgers and speculators to invest in stocks, which introduces the systematic risk (the covariance with equity returns) as an additional component of the risk premium. However, as already mentioned in our literature survey, the commodity futures systematic risk is empirically found to be small.

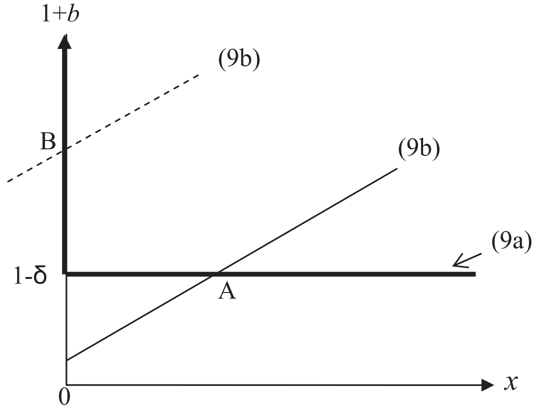


Figure 1. The basis (b), the amount carried over (x), and stock-out.

The equilibrium for the two-equation system (9a) and (9b) is described in Figure 1, with the horizontal axis measuring x and the vertical axis measuring (one plus) the basis $1 + b$ ($=S_0$/F). The graph of Equation (9a) is the L which consists of the segment of the vertical axis above $1-\delta$ and the horizontal line at $1-\delta$. Existence and uniqueness of equilibrium requires that, as shown in the figure, the graph of Equation (9b) be upward sloping, namely:

Assumption 1
$S(I-x)/[S_1^e(x) - \phi(x)]$ is an increasing function of x.

As inventory x increases (i.e., as more inventories are transferred to the next period, leaving less for the current period), the current spot price $S(I-x)$ rises. The expected next-period spot price $S_1^e(x)$ falls, but the *risk-adjusted* expected spot price $S_1^e(x) - \phi(x)$ could rise if the risk premium falls sharply with inventory. The above regularity condition says that a rise of the risk-adjusted expected spot price, if it occurs at all, should be proportionately less than the current spot price rise.

Comparative statics, which is about the effect of the model's exogenous variable I (the initial inventory level), can be conducted with Figure 1. The equilibrium is point A in the figure. Since the current spot price $S(I-x)$ declines with I, the graph of Equation (9b) shifts up and to the left if I is lower. It is routine to show that, under the above assumption, the amount of the leftward shift is less than the decline in I, so a one-unit decline in the initial inventory results in a less-than-one-unit decline in x. If I is sufficiently low, the graph looks like the dashed line, and the equilibrium is given at point B where $x = 0$ and $1 + b > 1 - \delta$. Therefore, there exists a threshold

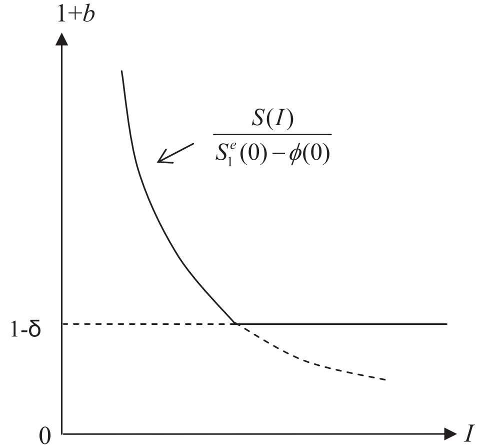


Figure 2. The basis (b) and the initial inventory (I).

level of initial inventory, denoted $\hat{I}$, below which a stock-out occurs.[8] Denoting the equilibrium x and b by $x(I)$ and $b(I)$ respectively, this graphical discussion establishes that

$$\text{For } 0 \leq I \leq \hat{I}, x(I) = 0; \text{ for } \hat{I} < I, 0 < x'(I) < 1. \tag{12a}$$

$$\text{For } 0 \leq I \leq \hat{I}, 1 + b(I) = \frac{S(I)}{S_1^e(0) - \phi(0)}; \text{ for } \hat{I} < I, 1 + b(I) = 1 - \delta. \tag{12b}$$

The function $1 + b(I)$ is graphed in Figure 2: for $I > \hat{I}$, it equals $1-\delta$; for the stock-out range of $0 \leq I < \hat{I}$, it is just an affine transformation of the spot demand curve. The behavior of the basis is also that of the convenience yield (see (1′)). This is gratifying: The central premise of the (both traditional and modern) Theory of Storage—that the convenience yield declines with inventory at a decreasing rate—is what the model predicts.

Given the function $x(I)$ just derived, comparative statics on the risk premium, the variable of our main concern, can be conducted easily. Using the first-order conditions above, the risk premium as a fraction of the futures price, $[E(\tilde{S}_1) - F]/F$, can easily be written as a function of x:

$$\text{risk premium} \equiv \frac{E(\tilde{S}_1) - F}{F} = \frac{\phi(x)}{S_1^e(x) - \phi(x)}. \tag{13}$$

[8] The threshold level $\hat{I}$ is determined by setting $1 + b = 1-\delta$ in (9a) and $x = 0$ in (9b).

Therefore, the risk premium is constant at $\phi(0)/[S_1^e(0) - \phi(0)]$ for the stock-out range of $0 \leq I \leq \hat{I}$. Outside the stock-out range $I > \hat{I}$, since $x(I)$ is strictly increasing, whether the risk premium declines with the initial inventory level I or not depends on the slope of the ratio $\phi(x)/[S_1^e(x) - \phi(x)]$. The slope's sign depends on further details of the model. As we will see (in Table IV), empirically, the risk premium declines with inventory. We therefore concentrate our attention to the case in which

Assumption 2

The ratio $\phi(x)/[S_1^e(x) - \phi(x)]$ declines with x.

As inventory x increases, the expected next-period spot price $S_1^e(x)$ declines, which raises the ratio. The assumption requires not only that the risk premium $\phi(x)$ fall but also that the fall be large enough to make up for the decline in the expected spot price.[9]

It is of interest how the risk premium is related to each of two endogenous variables of the model: The spot price volatility (defined as the square root of $Var(\tilde{S}_1) = Var(S(\tilde{z} + (1-\delta)x - \tilde{\varepsilon}))$ and S_0 (the current spot price). Since the volatility, too, is a function of x, its comparative statics is similar: Volatility is constant for the stock-out range of $0 \leq I \leq \hat{I}$; it declines outside the stock-out range if volatility declines with inventory x (which is the case for the example in the footnote above). Therefore, given it declines with inventory, the risk premium is a strictly increasing function of volatility.[10]

The analysis is cleaner with the current spot price S_0, which is a *strictly* decreasing function of I for all values of I including those in the stock-out range.[11] Thus the relation of the risk premium to I can be translated into one

[9] Here is an example in which both Assumptions 1 and 2 are satisfied. Assume no period 1 supply shock, so $\tilde{z} = z$ is not a random variable and consequently (11) becomes: $\phi(x) = \frac{\alpha\beta}{\alpha+\beta} Q\, Var[S(Q - \tilde{\varepsilon})]$, where $Q \equiv z + (1-\delta)x$. Assume that the price elasticity of spot demand is constant at η, so $S(q) = A \times q^{-1/\eta}$ and that the standard deviation of the demand shock $\tilde{\varepsilon}$ is proportional to Q, so $\tilde{\varepsilon} = Q \times \tilde{u}$ and $Q - \tilde{\varepsilon} = Q(1 - \tilde{u})$, where the variance of $\tilde{u}$ is a constant. Routine algebra produces the following. $S_1^e(x) = AQ^{-1/\eta}\mu$, $Var(\tilde{S}_1) = A^2 Q^{-2/\eta}\sigma^2$, and $\phi(x) = \frac{\alpha\beta}{\alpha+\beta} A^2 Q^{1-2/\eta}\sigma^2$, where $\mu \equiv E\big[(1-\tilde{u})^{-1/\eta}\big]$ and $\sigma^2 \equiv Var\big[(1-\tilde{u})^{-1/\eta}\big]$. A sufficient condition for Assumption 1 is that $S_1^e(x) - \phi(x)$ decline with x. It is satisfied if $1 \leq \eta < 2$ or if $\eta < 1$ and $Q > k$ where $k \equiv [(2-\eta)\frac{\alpha\beta}{\alpha+\beta}\frac{\sigma^2}{\mu} A]^{\eta/(1-\eta)}$. Assumption 2 is satisfied if and only if $\eta < 1$. Therefore, both Assumptions 1 and 2 are satisfied if $\eta < 1$ and $Q > k$.

[10] A more precise argument is as follows. Let y and v here be the risk premium and volatility. The comparative statics in the text is: $y = y_0$ if $0 \leq I \leq \hat{I}$ and $y = f(I) \leq y_0$, $f'(I) < 0$ if $\hat{I} < I$. $v = v_0$ if $0 \leq I \leq \hat{I}$ and $v = g(I) \leq v_0$, $g'(I) < 0$ if $\hat{I} < I$. So if we define a function $h : (0, v_0) \to \mathbb{R}$ by $h = f \circ g^{-1}$, then $y = h(v)$ is a strictly increasing function of v.

[11] For $0 \leq I \leq \hat{I}$, the derivative of $I - x(I)$ with respect to I is unity because $x(I) = 0$. The derivative is positive when $\hat{I} < I$ since $x'(I) < 1$.

to the spot price: The risk premium is constant at $\phi(0)/[S_1^e(0) - \phi(0)]$ and then starts to *increase* as the spot price rises above $S(\hat{I})$.

So far, we have assumed no demand shocks for the current period. If there is an additive demand shock ε_0 in period 0, we have $\Pi_0 = S(I - \varepsilon_0 - \bar{x}) \times (I - x)$, which can be written as $S_0 \times (I_0 - x) + S_0 \times \varepsilon_0$ where $S_0 = S(I_0 - \bar{x})$ and $I_0 \equiv I - \varepsilon_0$. The second term does not affect the first-order conditions because it is given from the viewpoint of a single hedger. Thus all the results go through if I is replaced by I_0. In particular, there remains a one-to-one mapping between I_0 and the spot price. That is, although I is now only a noisy measure of the true state of inventories I_0, the true state of inventories is fully reflected in the current spot price.

2.3 THEORETICAL PREDICTIONS FOR TESTING

We can summarize the theoretical predictions as follows.

An inverse and nonlinear basis-inventory regression: Thanks to the (continuously distributed) noise separating I and I_0, the conditional expectation of the basis given *observed* inventory I is a smoothed version of Figure 1. This smooth convex relation, being a conditional expectation, can be consistently estimated by nonlinear regression of the basis on the observed inventory level.

The risk premium-inventory regression: Likewise, if the risk premium is a decreasing function of I_0 (Assumption 2), the regression of the excess return (whose expected value is the risk premium) on I should inherit the sign of the slope. In particular, the risk premium, which is constant for the stock-out range, should be decreasing in the observed inventory level I.

The relationship between the risk premium and price-based signals:

The spot price: The current spot price fully reflects the true state of inventories I_0. If the risk premium is negatively related to I_0, it should be *positively* related to the spot price. In the empirical implementation of this test, we will normalize the current spot price by dividing it by the lagged spot price. That is, we will examine whether the lagged spot return is a predictor of the current futures excess return. The other predictor we examine is the lagged futures excess return, which is also a function of the current spot price. Thus we will be looking for *momentum* in the excess return.

Basis: Unlike the spot price, the basis only partially reflects the true state of inventories I_0 because it is constant for a range of the true state of inventories (see Figure 2, with I_0 replacing I). Nevertheless, the relationship should be positive.

Volatility: The risk premium should be positively related to volatility.

We now turn to testing these predictions. To anticipate our empirical evidence, we will find that all these theoretical predictions are borne out by data.

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) for commodities traded at the four North American Exchanges (NYMEX, NYBOT, CBOT, and CME), and Reuters and Bloomberg for commodities on the London Metals Exchange (LME). The details of these data are described in Appendix A. It updates the appendix in Gorton and Rouwenhorst (2006), who studied 36 commodity futures between 1959 and 2004. As in Gorton and Rouwenhorst (2006), we construct rolling commodity futures monthly excess returns by selecting at the end of each month the nearest to maturity contract that will not expire during the next month. That is, the excess return from the end of month t to the next month end is calculated as:

$$\frac{F_{t+1,T} - F_{t,T}}{F_{t,T}} \tag{14}$$

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 $t+1$. Also as in Gorton and Rouwenhorst (2006), we calculate the basis as:

$$\left(\frac{F_{1t}}{F_{2t}} - 1\right) \times \frac{365}{D_{2t} - D_{1t}}, \tag{15}$$

where F_{1t} is the nearest futures contract and F_{2t} is the next nearest futures contract; D_{1t} and D_{2t} are the number of days until the last trading date of the respective contracts.[12]

From the set of 36 commodities studied by Gorton and Rouwenhorst (2006), we drop the following five commodities: Electricity, because no

[12] If the nearest contract does not expire during the next month, then $F_{t,T}$ in (14) is F_{1t} in (15); otherwise it is F_{2t}. See Appendix A for more details.

inventory exists by its very nature, Gold and Silver because these are essentially financial futures and their inventory data would not be informative, and Sugar and Rough rice because we could not obtain monthly inventory series. This leaves us with 31 commodities, which are the object of our study.

For each of those 31 commodities, we determine the commodity-specific sample period by requiring that, prior to the start of the sample period, (a) there be enough trading history so that 12 successive monthly excess returns can be calculated, (b) the spot commodity price (see Appendix A for the definition) 12 months before be available and (c) monthly inventory data be available for 13 successive prior months. We impose (a) and (b) because we will use the 12-month prior excess and spot returns as signals for sorting commodities. We impose (c) because we will use, as the inventory measure, the ratio of inventory to its 12-month moving average, whose 1-month-lagged value will be used as a signal for sorting. Since our inventory data start from December 1969, the earliest starting month for the commodity-specific sample period is January 1971. The ending month is December 2010 (for which the excess return is from the end of December 2010 to the end of January 2011).

Columns 3–5 of Table I display information about the sample period for each of the 31 commodities. In addition to the 31 commodity futures, the first row of the table (labeled "EW index") shows the statistics for an equally weighed, monthly rebalanced, index of the commodity futures returns. It is the simple average for each month of the excess returns for those commodity futures whose commodity-specific sample period includes that month.

Columns 6–11 of the table summarize the distribution of excess returns measured in percent per annum. Although the sample period is slightly different than in Gorton and Rouwenhorst (2006), these summary statistics are qualitatively similar to those in their study. Of the 31 sample commodities, based on the sample arithmetic (geometric) average excess return, 22 (19) earned a positive risk premium over the sample. The equally weighted (EW) index earned an excess return of 5.75% per annum. Columns 9 and 10 show that the return distributions of commodity futures typically are skewed to the right and have fat tails. Column 11 indicates that commodity futures excess returns are on average positively correlated with the returns on other commodity futures, and that the correlations are on average low (0.16).

The last three columns of the table are about the basis. Column 12 shows that the basis has been negative on average for two-thirds of the commodities. An EW portfolio of the sample commodities had an average basis of −1.1% per annum, 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

Table I. Summary of futures excess returns and basis, 1971/1–2010/12

The table reports simple statistics of the monthly excess returns to individual commodity futures, defined by Equation (14), and the basis, defined by Equation (15), both expressed as percent per annum. Column 2 gives the commodity name. Columns 3 and 4 (labeled "Start" and "End") indicate the first and last months of the sample for the commodity (so, for example, if "Start" is 199611, the first observation of the excess return is from the end of November to the end of December 1996 and that for the basis is at the end of November 1996). Column 5 (labeled "*N*") gives the number of monthly observations in the sample, followed by the arithmetic and geometric average returns. The next columns give the annualized standard deviation (defined as the standard deviation of monthly returns multiplied by the square root of 12), skewness, and kurtosis, followed by the average pairwise correlation with the other commodities. The final three columns give the average, maximum, and minimum of the basis. The row labeled "Index" is for the EW portfolio. For each month, the index's excess return is the average of the excess returns (from the end of current month to the next) on the constituent commodities. The index's basis for the month is the average basis (at the end of the month) over the constituent commodities.

					Futures excess return						Basis		
Commodity group	Commodity	Start	End	*N*	Arithm mean	Geom. mean	Std. dev	Skewness	Kurtosis	Corr w/others	Arithm mean	Max	Min
Index	EW index	197101	201012	480	5.75	4.61	15.2	0.48	7.27	0.46	−1.1	47.0	−27.2
Metals	Copper	197101	201012	480	9.75	5.71	28.7	0.47	5.96	0.23	0.3	114.4	−24.5
	Platinum	199611	201012	170	14.89	12.31	22.3	−0.91	7.58	0.23	1.8	22.4	−13.1
	Palladium	199611	201012	170	19.97	12.38	39.4	0.35	5.15	0.18	−0.6	57.6	−7.3
	Zinc	199001	201012	252	1.89	−1.54	26.1	0.00	4.78	0.19	−4.6	48.3	−12.6
	Lead	199001	201012	252	7.03	2.87	28.9	0.15	3.95	0.15	−3.2	78.1	−18.5
	Nickel	198902	201012	263	8.60	2.44	35.3	0.24	3.56	0.16	0.7	45.2	−7.6
	Aluminum	198806	201012	271	−2.72	−4.90	20.8	−0.03	3.72	0.21	−4.4	40.0	−12.9
	Tin	199007	201012	246	9.35	7.03	21.8	0.51	4.63	0.20	−0.8	28.6	−8.8
Softs	Cotton	200309	201012	88	7.75	2.30	33.2	0.11	3.14	0.25	−11.1	35.0	−35.0
	Cocoa	197101	201012	480	8.82	3.73	32.6	0.74	4.38	0.10	−1.1	82.0	−33.5
	Orange juice	199104	201012	237	−2.46	−6.85	29.9	0.50	4.24	0.11	−9.2	45.2	−39.9
	Lumber	197101	200610	430	0.21	−4.27	30.1	0.42	4.33	0.01	−5.7	119.5	−71.5
	Coffee	199801	201012	156	−3.84	−9.22	33.4	0.72	3.52	0.16	−12.3	25.5	−31.0

(continued)

Table I. Continued

Commodity group	Commodity	Start	End	N	Futures excess return: Arithm mean	Geom. mean	Std. dev	Skewness	Kurtosis	Corr w/others	Basis: Arithm mean	Max	Min
Grains	Wheat	197107	201012	474	−0.28	−3.95	27.5	0.78	5.58	0.20	−5.5	116.0	−36.4
	Corn	197507	201012	426	−4.71	−7.58	24.1	0.65	7.48	0.21	−10.0	184.3	−30.9
	Soybeans	197101	201012	480	5.54	1.50	29.2	1.40	11.74	0.24	−1.7	179.1	−24.1
	Soybean oil	197111	201012	470	7.86	2.76	33.1	1.44	9.39	0.22	−0.8	294.9	−27.6
	Soybean meal	197110	201011	470	9.70	4.20	35.0	2.27	18.72	0.19	1.5	290.4	−96.9
	Oats	197507	201012	426	−2.58	−7.56	33.2	2.52	24.38	0.19	−8.2	136.4	−42.7
Meats	Pork bellies	197101	201006	474	1.45	−5.59	37.9	0.52	4.43	0.11	4.8	103.4	−83.3
	Live cattle	197101	201012	480	5.05	3.38	18.2	−0.22	4.61	0.13	2.1	100.1	−71.7
	Lean hogs	197101	201012	480	5.40	1.65	27.4	0.14	4.19	0.12	−7.3	144.6	−207.0
	Feeder cattle	197211	201012	458	2.52	1.07	16.8	−0.50	5.73	0.08	0.9	52.6	−101.3
	Milk	199807	201012	150	−3.49	−5.19	18.1	−0.88	6.69	0.04	9.0	541.9	−293.5
	Butter	200609	201012	52	−7.24	−8.58	16.1	−1.18	8.34	0.06	−11.5	352.7	−166.8
Energies	Heating oil	197911	201012	374	8.90	4.21	30.9	0.42	4.55	0.20	7.5	391.3	−64.7
	Crude oil	198403	201012	322	12.59	6.86	34.1	0.39	5.55	0.20	3.1	82.6	−125.8
	Gasoline	198512	201012	301	17.87	11.51	36.2	0.57	5.73	0.19	11.7	202.5	−186.2
	Propane	198808	200907	252	24.79	15.49	47.5	3.65	36.71	0.16	9.5	414.5	−60.2
	Natural gas	199104	201012	237	−0.67	−14.13	52.6	0.54	3.83	0.09	−18.0	381.4	−322.4
	Coal	200207	201012	102	7.68	3.56	29.7	1.29	8.27	0.23	−7.5	111.1	−83.9

"contango". At the same time, the average excess return on the EW index has been positive (5.75% per annum), indicating a historical risk premium to the long side of a commodity futures position.

The observation that a positive risk premium can be earned when the market is in contango is 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 (also referred to as "backwardation") is sometimes viewed as a requirement for the existence of a positive risk premium to a long position in commodity futures markets. Theoretically, this view of practitioners is unwarranted. Equation (1) shows that only when inventories are sufficiently low and hence the convenience yield is sufficiently high to compensate the inventory holder for the cost of storage, can the spot price exceed the futures price. The sample average basis of −1.1% 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 expected *future* spot prices, rewarding the long side of the futures position for providing price insurance.[13]

Empirically, the practitioner's view is typically based on arguments such as that portrayed in Figure 3, which plots the average excess return (reported in Column 6 of Table I) against the average basis (reported in Column 12). A simple linear regression has an R^2 of 36%. However, this cross-sectional plot only suggests a positive relation between the risk premium and the basis, which, incidentally, is actually a prediction of the model of Section 2.2. It does not show that a positive "roll yield" is required for a positive risk premium. Indeed, the plot shows many commodities in the north-west orthant for which the risk premium is positive despite a negative roll yield.

The maximum and the minimum of the basis are in the last two columns of Table I. The wide range of time-series variation in the basis can be accounted partly for the measurement error due to our use of the nearest futures price for the spot price (see Equation (15)), but there are cross-sectional (across commodities) patterns that are consistent with the theory of Section 2.2. First, as was depicted in Figure 2, the negative of the unit storage cost (δ in the model) is the lower bound for the basis, which explains why the absolute value of the minimum basis is smaller for easy-to-store commodities such as Metals than for hard-to-store ones such

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

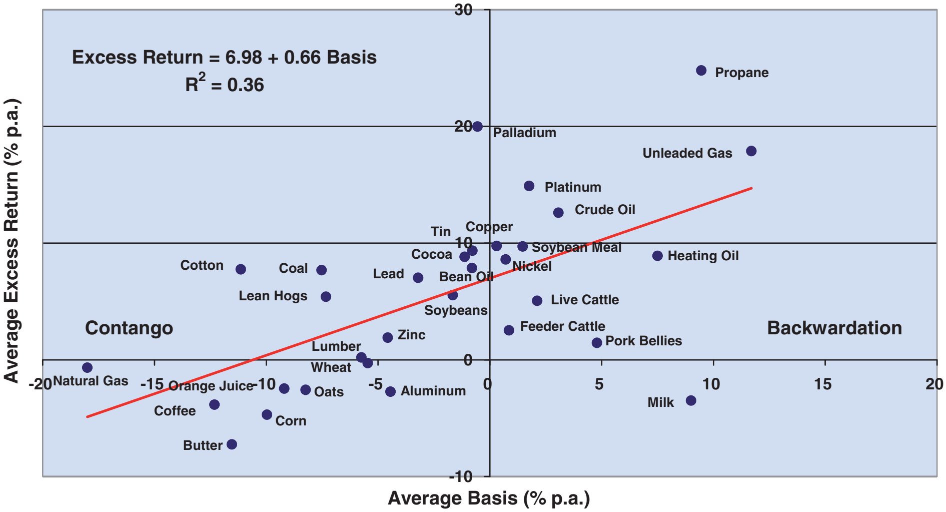


Figure 3. Plot of time-averaged excess return against time-averaged basis.

The figure plots the time-averaged excess return against the time-averaged futures excess return reported in Table I for individual commodity futures between 1990/12 (or sample starting date if later) and 2010/12. The basis is measured as the relative price difference between the two closest to maturity contracts, expressed as a percent per annum (see Equation (15) for a precise definition of the basis).

as Energies. Second, provided that inventories tend to be lower for those commodities with relatively high δ, theory predicts that there should be more incidents of stock-outs for hard-to-store commodities. This explains why the range of the basis variation is wider for Energies than for Metals.

3.2 INVENTORY DATA

There are many issues involved in compiling a data set 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 are 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 that is held at international locations but which 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 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 inventory data from a variety of sources for a number of commodities including the 31 commodities that are the object of our analysis. The earliest starting date is December 1969. A detailed description of these data is in Appendix B. Examination of the data reveals that the inventory time-series of most commodities contains a time-trend. To obtain a unit-free measure of inventory that has no trend, we define the *normal inventory level* at the end of month t, denoted as I_t^*, as the moving average of inventory levels over the previous 12 months $(I_{t-1}, I_{t-2}, \ldots, I_{t-12})$. We will call the ratio I_t/I_t^* the *normalized inventory level*.[14]

To illustrate the seasonal variation of inventories around these trends we ran a regression of $\log(I_t/I_t^*)$ on monthly dummy variables. Table II reports the regression results along with the autocorrelation of the residuals (which are de-trended and de-seasonalized inventories). The table illustrates two stylized facts about inventories. First, inventory levels are persistent, with the median first-order autocorrelation exceeding 0.85. Second, there are large cross-sectional differences in the seasonal behavior of inventories. Large seasonal variations are illustrated in Figure 4, which shows the monthly dummy coefficients reported in Table II for natural gas 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 harvested in late summer to fall in North America, and inventories therefore are lowest just prior to the harvest season and peak at the end of the harvest season. Contrary to corn, natural gas is produced throughout the year, but heating demand has a strong seasonal component that peaks during the winter months. During months of low demand, natural gas is stored in underground salt domes.

[14] Other methods of calculating normalized inventory, for example using a Hodrick–Prescott filter, do not materially affect the results.

Table II. Inventories and seasonality, 1971/1–2010/12

The table summarizes results from a regression of de-trended inventories on monthly dummies. De-trended inventories are defined as $\log(I) - \log(I^*)$ where $\log(I)$ is the log level of inventories and $\log(I^*)$ is the logarithm of a moving average of inventory levels over the previous 12 months. The final column gives the first-order autocorrelation of monthly de-trended and de-seasonalized inventories. The sample period for each commodity is the same as in Table I.

Commodity group	Commodity name	Coefficients of monthly dummies														
		January	February	March	April	May	June	July	August	September	October	November	December	R^2	*SER*	ρ
Metals	Copper	7.6	5.1	−3.2	−6.2	−7.6	−13.4	−8.9	1.3	4.8	0.9	0.2	5.0	0.02	46.3	0.94
	Platinum	−1.2	−4.5	0.0	−2.3	−11.0	−14.0	10.8	8.6	9.1	−3.0	−6.5	−5.3	0.03	41.1	0.81
	Palladium	−0.4	10.0	13.8	−3.7	−0.4	3.7	−8.1	−5.7	−2.5	−5.1	0.4	16.6	0.01	63.5	0.86
	Zinc	7.3	7.1	5.4	7.2	5.5	4.8	1.7	2.8	3.7	2.8	0.8	2.6	0.00	33.8	0.97
	Lead	−2.2	−3.8	−1.2	3.5	6.2	8.3	7.6	3.4	1.2	3.7	0.4	−0.1	0.01	36.1	0.93
	Nickel	10.6	4.9	6.2	3.4	7.1	−7.2	−8.3	−5.2	4.7	2.9	4.3	14.9	0.02	53.2	0.91
	Aluminum	11.5	12.6	10.5	9.1	8.6	8.5	6.0	3.5	3.6	2.1	4.9	6.9	0.01	36.4	0.96
	Tin	8.5	0.7	−1.5	−6.8	−9.9	−5.9	−4.1	0.4	−1.2	−5.9	−1.6	8.4	0.02	36.5	0.92
Softs	Cotton	−58.4	−23.3	9.2	21.8	31.8	15.3	−32.6	−55.4	−49.6	−54.4	−27.8	−50.5	0.11	90.9	0.88
	Cocoa	−10.7	−5.7	1.1	6.7	13.9	14.2	16.4	6.5	−0.4	−17.4	−23.8	−16.5	0.09	40.9	0.85
	OJ	0.9	6.1	7.4	17.3	21.7	16.2	7.4	−4.1	−17.1	−30.2	−30.8	−16.2	0.61	13.9	0.88
	Lumber	−1.1	0.2	0.6	0.1	−2.3	−2.1	−2.7	−2.9	−1.4	−0.4	−1.7	−1.1	0.03	6.6	0.77
	Coffee	7.5	12.6	12.4	10.7	19.6	17.3	18.0	11.7	10.3	6.6	3.7	0.7	0.02	36.5	0.92
Grains	Wheat	−4.2	−12.8	−20.3	−33.7	−44.3	−23.0	8.0	22.0	26.9	22.4	12.4	3.6	0.55	20.3	0.90
	Corn	22.9	20.5	17.1	7.2	−10.4	−26.7	−41.8	−51.6	−40.2	−1.3	22.7	21.9	0.55	24.8	0.82
	Soybeans	25.1	17.7	9.9	−5.4	−22.7	−41.0	−59.4	−92.1	−97.3	28.4	41.8	33.9	0.69	31.6	0.74
	Soybean oil	4.1	8.1	8.0	8.5	9.1	7.3	4.6	−1.5	−7.5	−12.6	−11.2	−4.3	0.13	19.7	0.94
	Soybean meal	5.0	3.2	0.6	2.4	7.0	−3.3	0.1	−17.3	−19.7	−2.4	7.0	6.2	0.12	22.9	0.50
	Oats	−9.2	−25.8	−19.7	−20.9	−34.2	−55.5	−44.4	−21.3	4.7	2.0	−7.7	4.9	0.07	66.4	0.74
Meats	Pork bellies	7.0	9.6	28.1	40.0	43.1	30.5	−11.3	−78.3	−129.8	−95.9	−30.8	5.4	0.74	32.4	0.82
	Live cattle	7.1	3.3	2.2	−0.1	−3.8	−5.3	−4.8	−5.1	−3.6	−0.6	2.4	6.2	0.11	12.2	0.88
	Lean hogs	1.6	3.6	7.8	16.0	14.3	5.9	−5.1	−16.1	−15.0	−7.9	−3.6	−3.7	0.34	13.7	0.87
	Feeder cattle	0.5	−3.4	−4.9	−4.6	−5.3	−4.0	−1.1	2.0	5.6	7.2	4.0	3.0	0.11	12.3	0.88
	Milk	−4.0	2.6	5.1	11.2	16.4	17.2	16.9	8.9	1.2	−7.9	−20.7	−19.3	0.70	8.3	0.90
	Butter	−19.0	−2.7	−0.4	12.8	19.2	18.0	16.8	7.1	−2.2	−21.7	−54.6	−51.3	0.76	14.4	0.89
Energies	Heating oil	2.8	−5.7	−15.2	−16.9	−12.0	−7.0	0.9	5.2	7.7	7.7	11.6	10.2	0.53	9.1	0.85
	Crude oil	−1.6	−1.0	1.7	3.4	3.5	1.8	0.5	−1.2	−2.9	−0.5	−0.5	−3.4	0.18	4.6	0.84
	Gasoline	5.7	5.1	0.6	−0.4	0.5	0.4	−1.1	−4.6	−2.1	−4.3	−1.4	0.1	0.43	3.4	0.70
	Propane	−21.9	−45.5	−50.8	−35.9	−13.7	3.3	16.0	23.9	27.9	26.7	22.0	4.4	0.82	13.0	0.84
	Natural gas	−16.3	−46.4	−61.4	−47.8	−24.3	−5.6	8.0	18.4	29.4	36.0	32.1	14.0	0.86	12.9	0.90
	Coal	−2.2	−3.4	0.2	5.5	7.7	5.9	1.3	−2.9	−3.1	0.4	2.7	0.8	0.21	6.9	0.96

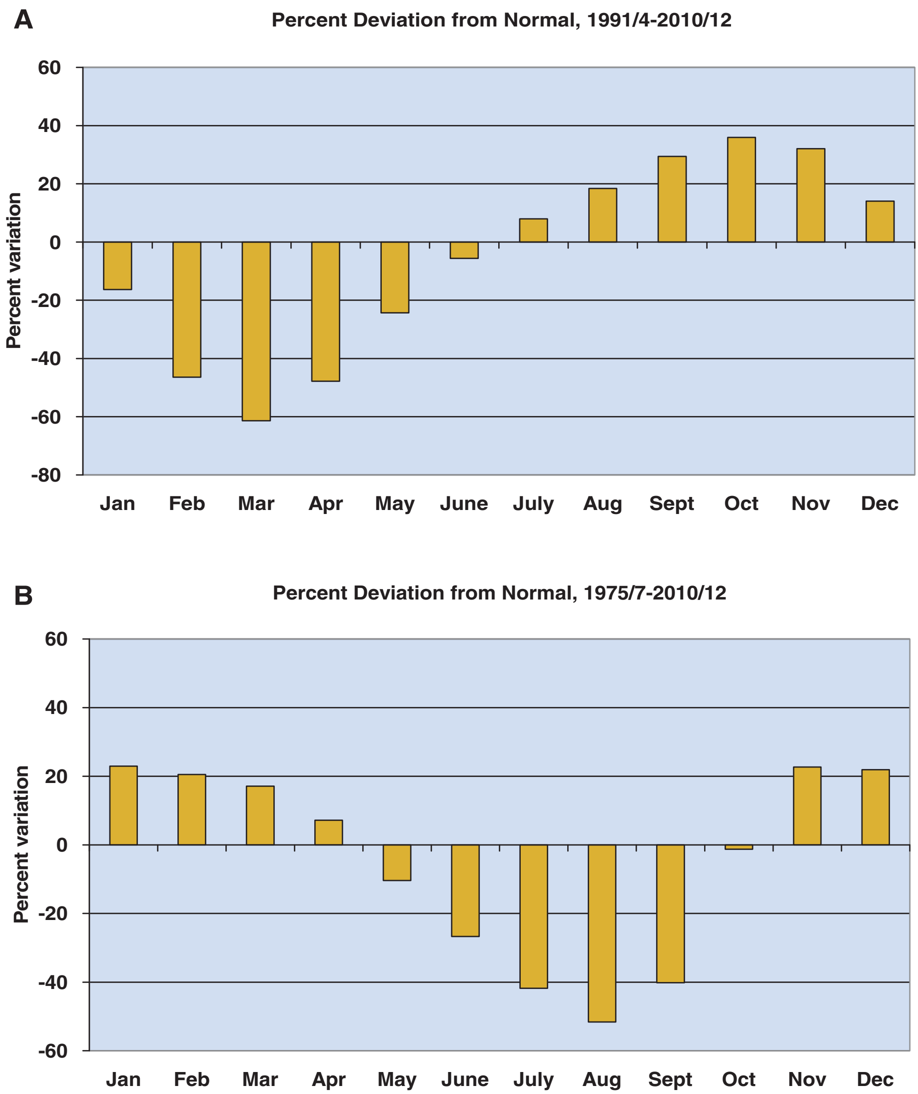


Figure 4. Seasonal variation of inventories.

The figure graphs the estimated coefficients of the monthly dummies reported in Table II. Panel A is for natural gas Inventories and Panel B for corn.

Industrial Metals inventories exhibit little seasonal variation as exhibited by the low regression R^2 given in Table II. 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.

Another noteworthy feature of Table II is the cross-sectional pattern of the variability of inventories measured by the standard error of the regression (*SER*). Because storage costs provide an incentive to economize on inventories, it would be the case that the variation of inventories is lower for commodities that are difficult to store, relative to commodities that are easy to store. This conjecture is indeed borne out in data, with the *SER* declining as we move from Metals to Energies in the table.

4. Inventories and Futures Prices

This section provides empirical evidence about the relationship between inventory levels and futures prices. In Section 4.1 we test the central assumption of the Theory of Storage (and a prediction of our theory of Section 2.2) that the basis is a declining and convex function 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. For each commodity we calculate the average basis for months when the normalized inventory I/I^* (defined in Section 3.2) is below 1 and above 1. The results are summarized in Panel A of Figure 5. 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.

To explore the nonlinear relationship between the basis and inventories we estimate the following regression:

$$\text{Basis} = \text{linear function of seasonal dummies} + h(I/I*) + \text{error}.$$

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 piecewise polynomial functions that fit together at "knots". In the case of cubic splines, the first and second derivatives are continuous at the knots.[15]

[15] The internal breakpoints that define the piecewise segments are called "knots". Let x_j ($j = 1,2,\ldots,J$, $0 < x_1 < x_2 < \ldots < x_J$) be those "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

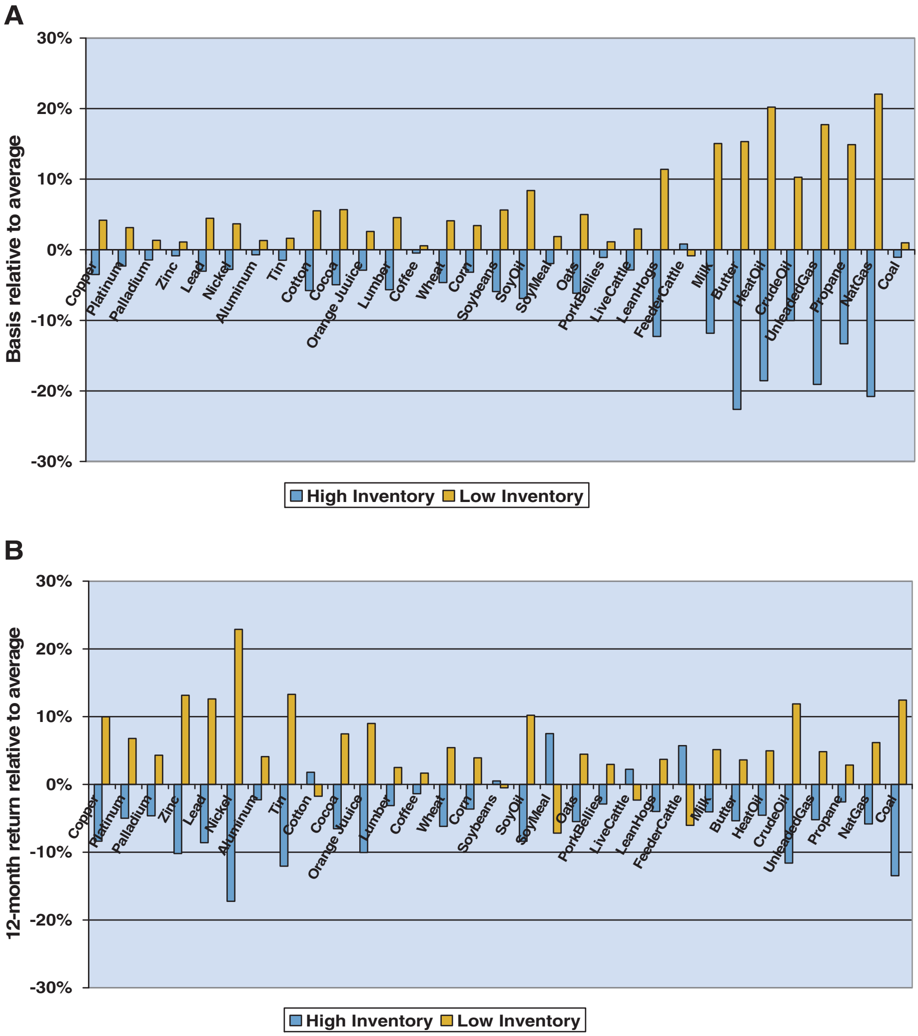


Figure 5. Inventories and price-based signals.

For each commodity, we divide the sample in months when the normalized inventory (I/I^*) 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-month return.

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 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 $h(I/I^*)$ at the normal level of inventories (i.e., $I/I^*=1$) as well as in situations when inventories fall 25% below ($I/I^*=0.75$). For each commodity, the sample period is the same as in Table I. The results of these tests are summarized in Table III, and illustrated in Panel A of Figure 6 for copper and Panel B for crude oil, with the same scale in both panels.

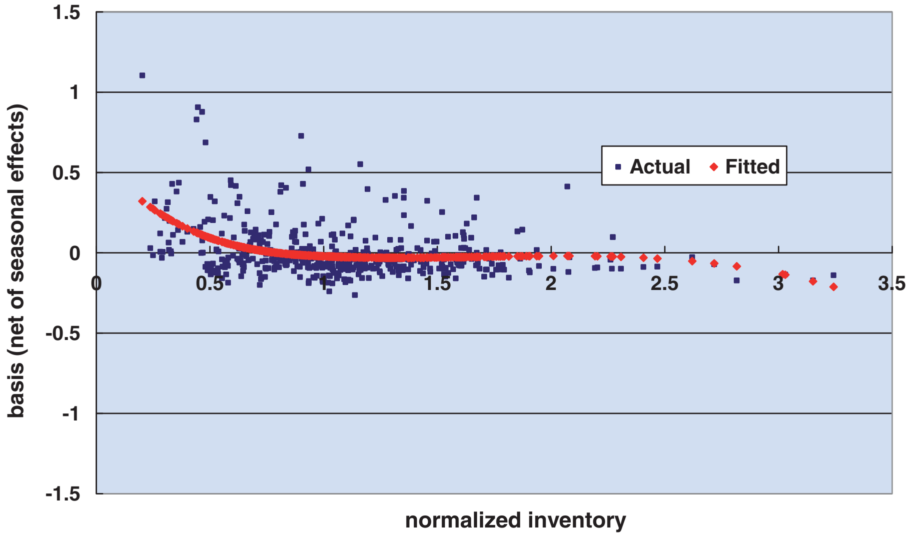
The second and third columns of Table III show that at the normal level of inventories, the estimated slope of the basis-inventory regression is negative for all commodities except four, and statistically significant at 5% for about a half of the commodities. For each commodity group, using pooled OLS we estimate the coefficients under the constraint that they are the same within groups. The relationship is particularly strong for Energies (the pooled OLS estimate for Energy is −1.86), whereas many industrial metals tend to have slope coefficients that are relatively small in magnitude (the pooled OLS estimate is −0.029). Industrial metals are relatively easy to store, and the normal inventory level I^* would be large relative to demand. Or, in terms of the theory of Section 2.2, I^* would be greater than the threshold inventory level $\hat{I}$ below which a stock-out occurs. By comparison, for Energy, which is more bulky and expensive to store, the opposite would be true. Storability also helps to explain why the slope coefficients for meats are on average smaller in magnitude than for commodities in the softs and grains groups. Cross-sectional differences in storability are therefore reflected in the sensitivity of the basis to inventories.

To examine the nonlinearity of the basis-inventory relationship, the fourth column of Table III reports the slope when inventories fall by 25% from their normal value. In the case of copper, for example, the estimated slope measured at the normal level of inventories equals −0.061 ($t=-0.82$) and steepens to −0.20 ($t=-2.50$) when inventories drop by 25%. This difference of 0.14, given in Column 6, is highly significant ($t=2.94$). Inspection of Columns 6 and 7 shows a pattern of steepening slopes for many commodities in the Metals and Softs group. The results are weaker for Grains, Meats, and Energies. This is because for those commodities the range of the normalized inventory is quite narrow. 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 6 for crude oil. This steep basis-inventory curve exhibited over a narrow inventory range is reflected in the cross-section pattern of the range of the basis noted for Table I and that of the inventory variability noted for Table II.

Table III. Futures basis and inventories

The table reports the results of a regression of the basis (defined in Equation (15)) on the normalized inventory 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 I. Columns 2–5 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 underlying the t-values are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). 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 correlation as well as cross-commodity correlation in the error terms. They also take into account the fact that the data are unbalanced, i.e., the starting month differs across commodities. See Appendix D.2 of for technical details about this joint estimation on an unbalanced panel.

Commodity	Slope at 1	t	Slope at 0.75	t	Difference	t	R^2
Metals group	−0.029	−1.19	−0.133	−5.39	0.104	5.59	
Copper	−0.061	−0.82	−0.202	−2.50	0.141	2.94	0.16
Platinum	−0.075	−3.86	−0.146	−7.58	0.070	4.63	0.58
Palladium	0.000	−0.01	−0.060	−2.17	0.060	3.63	0.32
Zinc	−0.059	−0.91	−0.166	−1.84	0.107	1.63	0.09
Lead	−0.068	−0.98	−0.311	−3.78	0.243	3.85	0.34
Nickel	−0.008	−0.20	−0.133	−3.41	0.125	5.01	0.41
Aluminum	−0.057	−1.14	−0.052	−0.97	−0.005	−0.13	0.06
Tin	−0.025	−0.99	−0.171	−5.45	0.146	6.50	0.41
Softs group	−0.234	−3.29	−0.403	−4.99	0.168	4.55	
Cotton	−0.054	−0.68	−0.136	−1.38	0.082	1.82	0.37
Cocoa	−0.158	−2.10	−0.386	−4.58	0.228	5.55	0.27
Orange juice	−0.526	−3.00	−0.875	−3.64	0.349	1.50	0.24
Lumber	−1.288	−1.76	3.564	1.18	−4.852	−1.54	0.16
Coffee	−0.040	−0.24	−0.436	−1.00	0.395	0.74	0.09
Grains group	−0.255	−5.27	−0.278	−5.24	0.023	0.91	
Wheat	−0.293	−2.23	−0.367	−2.32	0.074	0.68	0.21
Corn	−0.032	−0.33	−0.255	−2.10	0.223	2.23	0.22
Soybeans	−0.230	−2.99	−0.426	−4.17	0.196	3.73	0.27
Soybean oil	−0.552	−3.43	−0.747	−3.06	0.196	0.79	0.19
Soybean meal	−0.022	−0.16	−0.017	−0.09	−0.004	−0.02	0.11
Oats	−0.257	−2.62	−0.227	−2.24	−0.031	−0.88	0.13
Meats group	−0.325	−3.17	−0.398	−2.50	0.074	0.70	
Pork bellies	−0.301	−5.07	−0.390	−4.62	0.089	1.93	0.41
Live cattle	−0.148	−0.68	−2.285	−2.09	2.137	1.74	0.21
Lean hogs	−0.935	−3.17	−0.080	−0.11	−0.855	−1.00	0.52
Feeder cattle	0.113	0.65	−0.552	−0.65	0.665	0.70	0.10
Milk	4.406	2.04	−8.593	−1.18	13.000	1.55	0.16
Butter	1.711	1.28	−2.754	−1.52	4.465	2.07	0.56
Energies group	−1.861	−6.91	−2.618	−6.43	0.757	2.16	
Heating oil	−2.683	−5.89	−1.377	−1.24	−1.306	−1.03	0.40
Crude oil	−3.088	−5.78	−6.447	−0.38	3.359	0.20	0.37
Gasoline	−3.953	−3.02	−47.529	−0.64	43.576	0.58	0.35
Propane	−1.505	−4.05	−2.711	−6.09	1.206	2.78	0.46
Natural gas	−2.165	−3.28	−2.073	−2.66	−0.091	−0.15	0.49
Coal	0.114	0.11	−8.726	−0.35	8.840	0.35	0.08



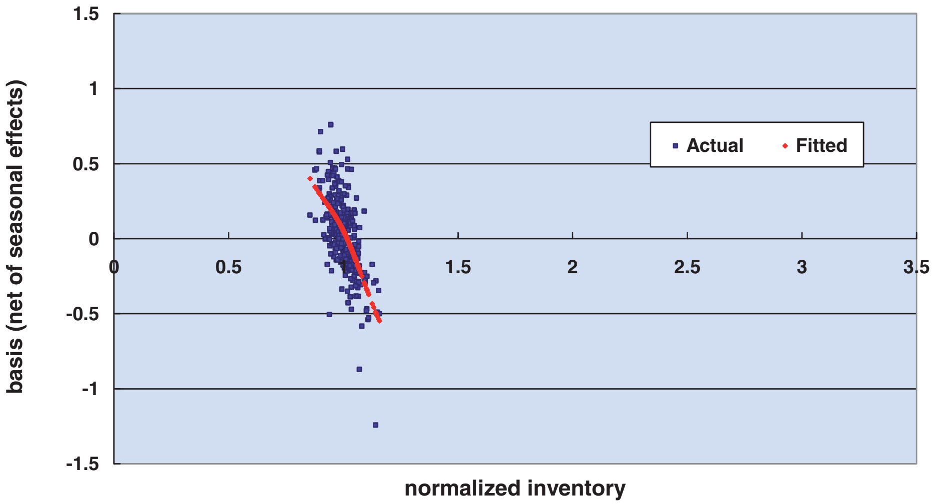


Figure 6. Plot of basis against normalized inventories.

The figure shows a scatter plot of the monthly observations of the futures basis against the normalized inventory (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.

Overall our results constitute a strong confirmation of the basic assumption of the Theory of Storage (and the prediction of our theory). 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.[16]

4.2 INVENTORIES AND FUTURES RISK PREMIUMS

Our theory of Section 2.2 provided the conditions under which the risk premium declines with the level of inventories. We now examine the prediction empirically. First, we perform a linear regression of the monthly excess return on the normalized inventory level I/I^* at the end of the prior month as well as monthly dummies. The results are reported in Table IV. Unlike in the basis-on-inventory regression of Table III, we only consider the linear specification because the excess return is a hard variable to predict, as evidenced in the low R^2 values in Table IV. As is apparent from the low t-values, the normalized inventory 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 significant negative and quantitatively large slope coefficients for all commodities except for the easy-to-store Metals. Taken together, Tables III and IV suggest that both the basis and the risk premium become sensitive to the normalized inventory level I/I^* when the normal inventory level I^* is low, i.e. the commodity is scarce.

In the second test of the negative relation, we examine a simple sorting strategy, whereby at the end of each month we cross-sectionally rank the commodities based on their level of normalized inventories I/I^*, lagged by one month to control for the publication lag of inventories. Because this lagged normalized inventory is observable in real time when sorting takes place, this trading strategy is feasible. We compare the average return of a portfolio of commodities in the top half in terms of normalized inventories (High) to the average return to a portfolio comprised of the commodities in the bottom half of this ranking (Low). The portfolios are equally weighted. Each of the two portfolios has the same number of commodities, thus benefiting equally from diversification.

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

Table IV. Commodity excess return and inventories

The table reports the results of a regression of the excess return from the end of the current month to the next (defined in Equation (14)) in percent *per annum* on the normalized inventory level I/I^* at the end of the current month, in addition to monthly dummies. The sample period for each commodity is the same as in Table I. The standard errors of the coefficient estimates underlying the t-values are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The estimates reported for each commodity group are the coefficient and t-statistics when coefficients are constrained to be the same. For technical details about this constrained estimation, see Appendix D.2.

Commodity	Coefficient of I/I^*	t	R^2
Metals group	−8.6	−0.93	
Copper	−25.0	−2.22	0.05
Platinum	0.8	0.05	0.11
Palladium	2.8	0.22	0.07
Zinc	−13.8	−0.67	0.04
Lead	−52.7	−2.58	0.09
Nickel	−6.3	−0.44	0.04
Aluminum	−0.4	−0.03	0.03
Tin	9.2	0.57	0.05
Softs group	−26.6	−2.16	
Cotton	−51.5	−2.59	0.17
Cocoa	−13.9	−1.16	0.03
OJ	−80.5	−1.82	0.07
Lumber	−109.1	−1.29	0.07
Coffee	−25.8	−1.66	0.07
Grains group	−17.2	−2.15	
Wheat	−49.2	−2.34	0.03
Corn	−1.6	−0.08	0.04
Soybeans	2.6	0.15	0.02
Soybean oil	−49.3	−1.61	0.02
Soybean meal	16.3	0.67	0.02
Oats	−22.2	−2.03	0.02
Meats group	−59.1	−4.10	
Pork bellies	−65.7	−3.77	0.06
Live cattle	−24.2	−1.00	0.01
Lean hogs	−82.0	−2.89	0.06
Feeder cattle	−6.1	−0.27	0.02
Milk	−171.6	−2.55	0.12
Butter	−117.8	−2.06	0.30
Energies group	−150.5	−2.13	
Heating oil	−117.0	−1.79	0.07
Crude oil	−149.2	−0.94	0.05
Gasoline	−114.4	−0.54	0.07
Propane	−184.2	−2.36	0.09
Natural gas	−190.4	−1.77	0.05
Coal	−273.4	−1.42	0.14

Since by construction the time-series mean of the normalized inventory does not deviate greatly from 1 for each commodity, easy-to-store commodities such as Metals are as likely to be included in the Low-inventory portfolio as hard-to-store ones such as Energies. That is, this sort is a way to exploit the time-series (negative) correlation between the risk premium and inventory documented by the commodity-by-commodity regression reported in Table IV. By design, it is possible that a metal is included in the Low portfolio while an Energy is excluded even though the latter commodity's normal inventory level is scarce and its risk premium higher than that of the former commodity. An alternative would be to use $I/\hat{I}$ (the ratio of inventory to the threshold level) rather than I/I^* as the signal. However, the threshold level, depending on both the depreciation rate and the inverse demand curve, would be hard to estimate reliably.

The results for sorting commodities by I/I^* are given in Table V. Panel A summarizes the annualized return distribution to these portfolios. The first three columns are for the full sample period of January 1971 (for which the excess return is from January to February 1971) to December 2010 (for which the excess return is from December 2010 to January 2011). The "High" ("Low") column reports statistics about the High (Low) inventory portfolio. The first three rows are the mean, the annualized standard deviation, and the *t*-value for the mean. The column labeled "Long–Short" is about a long–short portfolio created by taking long positions on commodities in the High inventory portfolio and *short* positions on those in the Low portfolio. Since the Long–Short portfolio takes positions on twice as many commodities as the High or the Low portfolios, its monthly return is equal to a half times the difference between the High portfolio return and the Low portfolio return. It is also approximately equal to the difference between the High or Low portfolio return and the EW index return.[17] Therefore, the *t*-value for the long–short portfolio (−2.78 here) can be used to test for out-performance by the Low portfolio over the High portfolio and also for out-performance over the EW index. The row labeled "Excess Return > EW (%)" is the percent of the sample months in which the monthly return is greater than the return from the EW portfolio. For 56% of the months, the Low inventory portfolio outperformed the EW portfolio. The next columns show that the performance difference between the inventory-sorted portfolios has been relatively stable during the more recent period. These results are consistent with our finding in Table IV that the risk premium declines with inventory.

[17] The approximation is exact if the number of commodities in the EW index is even.

Table V. Returns and characteristics of portfolios sorted on lagged inventories

At the end of each month the available commodities are ranked from high to low by the normalized inventory level I/I^*, lagged by one month to account for the publication lag in inventory data. The top half of the commodities is assigned to the High portfolio and the bottom half to the Low portfolio. Panel A of the table summarizes the annualized return distributions in percents of the High and Low portfolios. Panel B summarizes information about the average characteristics of the commodities in the High and Low portfolios. Portfolio characteristics include: The basis at the time of the ranking, the 12-month futures excess return prior to portfolio formation, the 12-month percentage change in the spot price prior to portfolio formation, volatility (the square root of the average squared daily excess returns of the month over which the excess return is calculated, multiplied by the square root of 365), de-meaned volatility (defined as the volatility minus the sample time-series mean of the volatility), and the positions of traders (measures as a percent of open interest at the time of sorting) as defined by the CFTC. To calculate the average in Panel B for each characteristic and for each High or Low portfolio, we first create a monthly series by calculating for each month the average of the characteristic over the constituent commodities in the portfolio. We then calculate the time-series mean of the monthly series. Panel B's columns measure the average characteristics thus calculated of the commodities in the High portfolio, the Low portfolio, and the t-statistic for the difference. The t-statistics are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The sample period for each commodity is the same as in Table I.

	Panel A: Statistics about excess return from t to $t+1$								
	$t=1971/1$–$2010/12$			$t=1986/1$–$2010/12$			$t=1990/12$–$2010/12$		
	High	Low	Long–short	High	Low	Long–short	High	Low	Long–short
Mean	2.03	8.93	−3.45	2.82	9.38	−3.28	1.44	8.86	−3.71
Standard deviation	18.59	15.25	7.58	14.80	13.21	6.27	14.19	13.29	6.02
t-statistic for the mean	0.63	3.21	−2.78	0.88	3.16	−2.55	0.40	2.59	−2.59
Excess return > EW (%)	43	56	43	44	56	41	43	56	42

	Panel B: Average portfolio characteristics at t or $t+1$								
	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference
Basis at t	−4.47	2.31	−7.39	−3.80	2.26	−6.10	−5.53	0.42	−5.72
Prior 12-month excess return at t	3.02	10.62	−4.49	2.31	9.90	−4.88	0.95	9.77	−4.83
Prior 12-month spot return at t	3.93	12.50	−6.77	3.18	12.02	−7.17	3.59	13.25	−6.58
Volatility at $t+1$	31.60	30.64	2.11	31.77	30.67	1.93	31.50	30.93	0.95
Demeaned volatility at $t+1$	0.71	−0.40	2.78	0.29	−0.73	2.57	0.10	−0.75	2.10
Commercials at $t+1$				−10.16	−10.22	0.07	−10.08	−11.04	1.17
Noncommercials at $t+1$				6.11	7.47	−2.86	6.47	8.24	−3.16
Nonreportable at $t+1$				4.05	2.75	2.61	3.61	2.80	1.61

In Panel B of Table V, we summarize various characteristics of the commodities in the inventory-sorted portfolios. The first line of Panel B confirms our findings so far: the Low inventory portfolio selects high-basis commodities, with the difference between the average basis of the Low and High inventory portfolios equal to 7.39% (= 4.47% + 2.31%) with a t-value of 7.39. The next two lines confirms the prediction of the model of Section 2.2 that Low inventory commodities also have higher prior 12-month futures excess return and prior 12-month spot return than High inventory commodities. Over the full sample, the prior 12-month futures excess return difference is about 7.6% per annum ($t = 4.49$).

We also report two measures of our model's spot price volatility (the square root of $Var(\tilde{S}_1)$) in the High and Low inventory portfolios. One is the square root of the average squared daily excess returns (multiplied by the square root of 365, see Appendix A for a precise definition) during the *next* month, meant to measure the market's evaluation, as of the end of the current month, of the variability of the spot price at the end of the next month. Comparison of this measure of volatility gives a sense whether Low inventory commodities have lower volatility than High inventory commodities. Because there are large cross-sectional differences in unconditional volatilities across commodities, we also report de-meaned volatility, whereby for each commodity we subtract the mean of volatility over the full sample. Comparison of the de-meaned volatility characteristic gives a sense whether individual commodity volatility changes as it migrates from low to high inventory states. Panel B of Table V shows that, regardless of the volatility measure, the High inventory commodities have relatively *high* spot price volatility. So the model's prediction that the spot price volatility should decline with inventory is not borne out by data. This is the only finding of the article that is inconsistent with theory.

Finally, in preparation of the "hedging pressure" regression of Section 6, the last three lines of Panel B summarize the positions of traders in futures markets. Over the years, the Commodity Futures Trading Commission (CFTC) has been publishing data on the positions of futures traders in the *Commitments of Traders Reports*. For each commodity, large traders are classified as "Commercials" or "Noncommercials" and smaller traders are called "Nonreportables".[18] The CFTC omits information about the specific

[18] The category of "nonreportable positions" includes either commercial or noncommercial positions that are below the reporting limits set by the CFTC. These would include either small hedgers or speculators therefore. For the exact definitions see http://www.cftc.gov/opa/backgrounder/opacot596.htm. See also Ederington and Lee (2001) for a discussion about the accuracy of the classifications.

identities of traders, but it has become customary in the academic literature to view Commercials as hedgers and Noncommercials as speculators. The empirical measure of a commodity's "hedging pressure" used in the literature is the ratio of the net short position collectively taken by "Commercials" to open interest in that commodity. Historical records since January 1986 of this CFTC report are available from the CFTC website, and our calculation is for the period since then. Of our 31 commodities, CFTC positions information for 22 commodities can be calculated.[19] Unlike the basis and prior returns, the position we use here is contemporaneous with the excess return. That is, the position at the end of the *next* month is paired with the excess return from the current month to the next. The averages for the three trader categories displayed in Panel B are averages over those commodities in the High or Low portfolio whose CFTC positions information is available. They show that Commercial traders are net short in commodity futures markets and that their net positions are slightly less negative for High inventory commodities (although the difference is not statistically significant).

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

As noted in Section 2.2, the level of inventories is a noisy measure of the true state of inventories because of demand shocks. Also, there is a conceptual question about the relevant inventory measure mentioned in Section 3.2. These considerations motivate us to examine other signals of the current state of inventories.

As we already noted for Table V, low-inventory commodities have a higher basis, higher prior excess and spot returns. For the basis, we have already shown the negative association in Panel A of Figure 5 as well as in Table III. For prior returns, Panel B of Figure 5 illustrates the relation between inventories and 12-month prior futures excess 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 the normalized inventory level I/I^* is above unity and when it is below unity. The Figure illustrates that for most commodities, high normalized inventories are associated with low futures returns over the prior year,

[19] The CFTC report does not cover those commodities in our sample that are traded on the LME. Those LME commodities are: Zinc, Lead, Nickel, Aluminum, and Tin. Also, the report has only spotty positions information for Butter and Corn. The list of those 22 commodities with usable CFTC positions information and the period of data availability can be found in Table X. For more details, see Appendix C.

whereas low inventory states are associated with high prior 12-month futures returns. Taken together, Table V and Figure 5 show that prior futures returns and the basis are informative price-based signals of the level of inventories.

In the remainder of this section, we report the performance of portfolio strategies that sort commodities on price-based signals of inventories such as the basis, the prior futures excess return, the prior spot return, and volatility. The procedure for forming the High and Low portfolios and for calculating the portfolio returns are the same as in the inventory-sorted strategy of the previous section. The performance and characteristics of the portfolios are given in Tables VI–IX.

Panel A of Table VI summarizes the returns on the portfolios formed by sorting commodities based on the basis. Theory predicts that a high basis is associated with a low inventory level. So we should expect the High Basis portfolio to outperform the Low Basis portfolio. Indeed, the table shows that, over the full sample period since 1971, the return difference between the High Basis portfolio and the Low Basis portfolio was 10.64% (= 10.95%–0.31%) with a *t*-value of 3.92. The High Basis portfolio outperformed the EW index in about 56% of the months. The outperformance over the EW index comes with only a slight increase in volatility: The annualized standard deviation of the High Basis portfolio is 17.8%, which is only slightly higher than that of the EW index of 15.2% reported in Table I.

Panel B of Table VI reports several characteristics of the basis-sorted portfolios. Theory predicts that the High Basis portfolio selects commodities that have below normal inventories, high prior 12-month futures returns, high spot prices (measured relative to the same time last year) and high volatility. These predictions are indeed borne out by the data: The High Basis portfolio selects commodities with low inventories ($t = -10.79$), high futures excess returns during the 12-month period prior to portfolio formation ($t = 11.49$), and high spot prices relative to the same time a year prior ($t = 9.94$). In addition, High Basis states are associated with above average commodity volatility.

The right two-thirds of Table VI examines two more recent subperiods. These panels show that these returns and portfolio characteristics have been relatively stable overall. The last three rows of Panel B summarize the CFTC positions of traders in the basis-sorted portfolios. Commercials are on average net short in both the High and Low Basis portfolios, and Noncommercials and Nonreportables are net long. Noncommercials are over-weighted in the High Basis commodities, and the reverse holds for the Nonreportable positions. There is no significant difference between the positions of Commercials between the two portfolios.

Table VI. 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 by the futures basis. The top half of the commodities are assigned to the High portfolio and the bottom half to the Low portfolio. Panel A of the table summarizes the annualized return distributions in percents of the High and Low portfolios. Panel B summarizes information about the average characteristics of the commodities in the High and Low portfolios. Portfolio characteristics include: The average percentage deviation of the actual to the normal inventory level at the time of ranking, the 12-month futures excess return prior to portfolio formation, the 12-month percentage change in the spot price prior to portfolio formation, volatility (the square root of the average squared daily excess returns of the month over which the excess return is calculated, multiplied by the square root of 365), de-meaned volatility (defined as the volatility minus the sample time-series mean of the volatility), and the positions of traders (measures as a percent of open interest at the time of sorting) as defined by the CFTC. To calculate the average in Panel B for each characteristic and for each High or Low portfolio, we first create a monthly series by calculating for each month the average of the characteristic over the constituent commodities in the portfolio. We then calculate the time-series mean of the monthly series. Panel B's columns measure the average characteristics thus calculated of the commodities in the High portfolio, the Low portfolio, and the *t*-statistic for the difference. The *t*-statistics are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The sample period for each commodity is the same as in Table I.

Panel A: Statistics about excess return from t to $t+1$

	$t=1971/1–2010/12$			$t=1986/1–2010/12$			$t=1990/12–2010/12$		
	High	Low	Long–short	High	Low	Long–short	High	Low	Long–short
Mean	10.95	0.31	5.32	10.15	1.82	4.17	10.27	0.12	5.07
Standard deviation	17.81	16.58	7.90	14.45	14.04	6.98	14.45	13.27	6.31
t-statistic for the mean	3.32	0.12	3.92	3.14	0.61	3.13	2.74	0.04	3.63
Excess return > EW (%)	56	44	51	57	43	50	57	43	49

Panel B: Average portfolio characteristics at t or $t+1$

	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference
Inventory ($100 \times \log(I/I^*)$) at t	−9.41	3.61	−10.79	−6.82	3.06	−8.78	−6.89	2.78	−7.47
Prior 12-month excess return at t	19.28	−5.32	11.49	17.32	−4.95	14.43	16.34	−5.64	11.76
Prior 12-month spot return at t	15.28	1.17	9.94	14.14	1.16	9.15	14.99	1.85	7.93
Volatility at $t+1$	31.70	30.46	2.47	31.80	30.59	1.83	31.74	30.74	1.32
Demeaned volatility at $t+1$	0.88	−0.56	3.56	0.86	−1.37	4.65	0.87	−1.46	4.43
Commercials at $t+1$				−10.39	−10.19	−0.20	−11.46	−10.06	−1.29
Noncommercials at $t+1$				8.41	5.60	4.06	9.45	5.77	4.72
Nonreportable at $t+1$				1.98	4.59	−5.13	2.01	4.29	−4.40

Table VII. Returns and characteristics of portfolios sorted on the prior 12-month futures excess return

At the end of each month the available commodities are ranked from high to low by prior 12-month futures excess return. The top half of the commodities are assigned to the High portfolio and the bottom half to the Low portfolio. Panel A of the table summarizes the annualized return distributions in percents of the High and Low portfolios. Panel B summarizes information about the average characteristics of the commodities in the High and Low portfolios. Portfolio characteristics include: The average percentage deviation of the actual to the normal inventory level at the time of ranking, the basis at the time of the ranking, the 12-month percentage change in the spot price prior to portfolio formation, volatility (the square root of the average squared daily excess returns of the month over which the excess return is calculated), de-meaned volatility (defined as the volatility minus the sample time-series mean of the volatility), and the positions of traders (measures as a percent of open interest at the time of sorting) as defined by the CFTC. To calculate the average in Panel B for each characteristic and for each High or Low portfolio, we first create a monthly series by calculating for each month the average of the characteristic over the constituent commodities in the portfolio. We then calculate the time-series mean of the monthly series. Panel B's columns measure the average characteristics thus calculated of the commodities in the High portfolio, the Low portfolio, and the t-statistic for the difference. The t-statistics are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The sample period for each commodity is the same as in Table I.

	Panel A: Statistics about excess return from t to $t+1$								
	$t=1971/1$–$2010/12$			$t=1986/1$–$2010/12$			$t=1990/12$–$2010/12$		
	High	Low	Long–short	High	Low	Long–short	High	Low	Long–short
Mean	11.79	−0.15	5.97	11.78	0.84	5.47	10.91	−0.38	5.65
Standard deviation	18.55	17.34	9.16	16.19	13.85	8.28	15.00	13.52	7.13
t-statistic for the mean	3.56	−0.05	4.40	3.39	0.28	3.60	2.81	−0.12	3.59
Excess return > EW (%)	56	44	51	58	41	51	59	40	52

	Panel B: Average portfolio characteristics at t or $t+1$								
	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference
Inventory ($100 \times \log(I/I^{*})$) at t	−7.22	1.81	−6.51	−5.97	2.40	−6.44	−7.04	3.09	−7.07
Basis at t	7.37	−9.35	15.72	7.13	−8.68	13.94	5.29	−10.40	12.34
Prior 12-month spot return at t	26.28	−9.57	22.33	25.69	−10.50	24.72	26.73	−9.88	21.10
Volatility at $t+1$	31.91	30.44	1.87	32.15	30.34	1.89	32.32	30.17	2.03
Demeaned volatility at $t+1$	1.16	−0.70	2.97	0.94	−1.37	3.42	0.90	−1.50	3.70
Commercials at $t+1$				−12.53	−8.20	−3.25	−13.45	−8.08	−3.70
Noncommercials at $t+1$				10.07	3.71	8.48	11.13	3.82	8.82
Nonreportables at $t+1$				2.46	4.49	−2.63	2.32	4.26	−2.47

Table VIII. 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 by 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 portfolio and the bottom half to the Low portfolio. Panel A of the table summarizes the annualized return distributions in percents of the High and Low portfolios. Panel B summarizes information about the average characteristics of the commodities in the High and Low portfolios. Portfolio characteristics include: The average percentage deviation of the actual to the normal inventory level at the time of ranking, the basis at the time of the ranking, the 12-month futures excess return prior to portfolio formation, volatility (the square root of the average squared daily excess returns of the month over which the excess return is calculated), de-meaned volatility (defined as the volatility minus the sample time-series mean of the volatility), and the positions of traders (measures as a percent of open interest at the time of sorting) as defined by the CFTC. To calculate the average in Panel B for each characteristic and for each High or Low portfolio, we first create a monthly series by calculating for each month the average of the characteristic over the constituent commodities in the portfolio. We then calculate the time-series mean of the monthly series. Panel B's columns measure the average characteristics thus calculated of the commodities in the High portfolio, the Low portfolio, and the t-statistic for the difference. The t-statistics are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The sample period for each commodity is the same as in Table I.

Panel A: Statistics about excess return from t to $t+1$

	$t=1971/1–2010/12$			$t=1986/1–2010/12$			$t=1990/12–2010/12$		
	High	Low	Long–short	High	Low	Long–short	High	Low	Long–short
Mean	11.65	−0.23	5.94	12.80	−0.48	6.64	10.63	−0.27	5.45
Standard deviation	18.84	17.02	9.23	16.69	14.01	8.95	15.32	13.37	7.36
t-statistic for the mean	3.48	−0.08	4.17	3.65	−0.16	3.82	2.79	−0.08	3.12
Excess return > EW (%)	58	41	51	61	38	50	61	39	49

Panel B: Average portfolio characteristics at t or $t+1$

	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference
Inventory ($100 \times \log(I/I^*)$) at t	−8.68	3.21	−8.96	−7.46	3.87	−8.81	−8.19	4.29	−8.83
Basis t	4.62	−6.65	10.33	4.83	−6.30	10.09	3.08	−8.06	9.27
Prior 12-month excess return at t	27.22	−13.11	16.11	25.93	−13.57	23.41	25.00	−14.25	20.38
Volatility at $t+1$	31.91	30.30	1.96	32.01	30.51	1.45	32.28	30.23	1.95
Demeaned volatility at $t+1$	1.05	−0.67	2.73	0.63	−1.03	2.24	0.59	−1.18	2.67
Commercials at $t+1$				−13.25	−7.14	−6.11	−14.21	−6.97	−7.42
Noncommercials at $t+1$				10.18	3.51	12.16	11.12	3.77	12.66
Nonreportables at $t+1$				3.06	3.62	−0.79	3.09	3.20	−0.15

Table IX. Returns and characteristics of portfolios sorted on volatility

At the end of each month the available commodities are ranked from high to low by de-meaned volatility, defined as the deviation from the time-series mean of volatility (the square root of the average squared daily excess returns of the month over which the excess return is calculated). The top half of the commodities are assigned to the High portfolio and the bottom half to the Low portfolio. Panel A of the table summarizes the annualized return distributions in percents of the High and Low portfolios. Panel B summarizes information about the average characteristics of the commodities in the High and Low portfolios. Portfolio characteristics include: The average percentage deviation of the actual to the normal inventory level at the time of ranking, the basis at the time of the ranking, the 12-month futures excess return prior to portfolio formation, the 12-month percentage change in the spot price prior to portfolio formation, and (the square root of the average squared daily excess returns of the month over which the excess return is calculated), and the positions of traders (measures as a percent of open interest at the time of sorting) as defined by the CFTC. To calculate the average in Panel B for each characteristic and for each High or Low portfolio, we first create a monthly series by calculating for each month the average of the characteristic over the constituent commodities in the portfolio. We then calculate the time-series mean of the monthly series. Panel B's columns measure the average characteristics thus calculated of the commodities in the High portfolio, the Low portfolio, and the t-statistic for the difference. The t-statistics are by the Newey–West method for correcting error serial correlation with a bandwidth of 12 months (see Appendix D.1 for more details). The sample period for each commodity is the same as in Table I.

Panel A: Statistics about excess return from t to $t+1$

	$t=1971/1$–$2010/12$			$t=1986/1$–$2010/12$			$t=1990/12$–$2010/12$		
	High	Low	Long–short	High	Low	Long–short	High	Low	Long–short
Mean	11.47	0.65	5.41	11.83	0.71	5.56	10.28	0.43	4.93
Standard deviation	22.54	11.67	9.39	19.02	10.04	8.58	17.27	10.26	6.94
t-statistic for the mean	3.01	0.30	3.64	3.01	0.29	3.45	2.43	0.15	3.12
Excess return > EW (%)	56	45	48	58	42	50	58	43	48

Panel B: Average portfolio characteristics at t or $t+1$

	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference	High	Low	t-statistic for the difference
Inventory ($100 \times \log(I/I^*)$) at t	−3.63	−1.92	−1.42	−3.28	−0.47	−2.53	−3.76	−0.29	−2.73
Basis at t	0.54	−2.49	3.45	1.64	−3.14	4.92	−0.38	−4.69	3.89
Prior 12-month excess return at t	11.74	2.14	4.88	9.89	2.35	4.89	9.41	1.27	4.80
Prior 12-month spot return at $t+1$	11.51	4.98	4.59	10.21	5.02	3.75	11.49	5.34	4.17
Volatility at $t+1$	39.20	23.05	23.03	39.37	23.18	19.08	39.04	23.50	19.03
Commercials at $t+1$				−9.96	−10.39	0.62	−10.42	−10.73	0.39
Noncommercials at $t+1$				7.25	6.36	1.87	7.94	6.83	1.97
Nonreportables at $t+1$				2.71	4.03	−3.43	2.48	3.91	−3.53

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 repeat the portfolio sorts after subtracting the full sample mean from the basis for each commodity.[20] By construction, much as in the sort by the normalized inventory, easy-to-store commodities are as likely to be included in the High or Low inventory portfolio as hard-to-store ones. This sort therefore exploits only the time-series correlation between the risk premium and the basis; it does not exploit the cross-section correlation (shown in Figure 3) that hard-to-store commodities tend to have higher risk premiums. Not surprisingly, then, the out-performance by the High over the Low (de-meaned) Basis portfolios of 8.06% ($t = 2.73$) (this result is not reported in the table) is less than the return differential of 10.64% with sorting on the raw basis. The annualized standard deviation of the High or Low portfolio return is about the same with this de-meaned sorting. Another basis-related signal we considered is motivated by the result depicted in Figure 2 that the basis has a lower bound equal to the negative of the depreciation rate. If the sort is by the basis after subtracting the minimum basis reported in the last column of Table I (thus, for example, for natural gas, we add 322.4% to its basis), the High portfolio is now heavily overrepresented by hard-to-store commodities such as Energies and Meats. The return differential (not reported in Table VI) is small: 5.16% ($t = 1.74$). The use of the raw basis without adjustment for the sample mean or the minimum, besides being a feasible strategy, exploits both the time-series and cross-section correlation between the basis and the risk premium.

Table VII summarizes the returns from sorting commodities on Futures Momentum, measured as the prior 12-month futures excess return. Although momentum has been documented at horizons ranging from 1 month to 1 year, we chose to report results for a relatively long prior return interval (e.g., see Pirrong, 2005; Shen, Szakmary, and Sharma, 2007). Based on the empirical evidence of Table II that inventories are slow to adjust, we expect relatively distant prior shocks to inventories to carry information about current inventories. Because many commodities have distinct annual seasonal variation in production, we include a history of one year.

Panel A shows that High Momentum commodities have outperformed a portfolio of Low Momentum commodity futures by 11.94% (= 11.79% + 0.15%) per annum ($t = 4.40$). Panel B shows that Momentum

[20] This is not a feasible trading strategy because the full sample mean cannot be calculated until the end of the sample period.

portfolios take positions in similar commodities as the basis-sorted portfolios. In particular, the High Momentum portfolio selects commodities with below normal inventories and relatively high bases, whereas 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 our theory. This is reflected in the correlation between the returns to High Basis and High Momentum portfolios (not reported in the table), which is 0.85 over the full sample period. The positions of traders in Panel B reveal that Commercials increase their short positions in commodities that experience price increases, whereas Noncommercials take larger long positions following a price run-up. Unlike sorting by inventories and the basis, the difference in the net position taken by Commercials is statistically significant.

Table VIII 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 with the same time a year ago. Panel A of the Table VII shows that the results for portfolios sorted on Spot Momentum are very similar to those sorted on Futures Momentum. The High Spot Momentum portfolio has outperformed the Low Momentum portfolio by 11.88% per annum ($t = 4.17$) over the full sample. And High Spot Momentum commodities have relatively low inventories, a high basis, high futures momentum, and above average volatility. The positions of traders in Panel B shows that Commercials hedge more after spot prices have increased, and that much of the liquidity to them is provided by the Noncommercials.

Finally, the results from sorting commodities into portfolios based on their volatility are summarized in Table IX. As mentioned before, our ability to detect volatility effects may be weakened by the fact that different commodities may have different mean levels of volatility. This would affect sorts of the type we performed above. For example, the arrival of spring marks the end of a period of peak demand for natural gas as well as the start of the growing season for wheat. Uncertainty about wheat prices is likely to rise relative to uncertainty about natural gas prices. However, if wheat were to replace natural gas in the High Volatility portfolio during the spring, the volatility of the average commodity in the High Volatility portfolio is likely to fall relative to the average volatility of commodities in the Low Basis portfolio. This is because natural gas has much higher unconditional volatility than wheat (which can be surmised from the standard deviation of *monthly* futures return reported in Table I), despite the fact that wheat prices become more volatile during the growing season, and natural gas prices become less volatile after the end of winter. This is why we reported de-meaned volatilities among the characteristics in the lower panels of Tables V–VIII. Overall, the volatility sorts are correlated with the other characteristics in ways that are consistent with the other tables. i.e., increased volatility is associated with lower inventories, high basis, and high momentum.[21]

The main conclusion from Tables V–IX is that risk premiums of commodity futures vary with the state of inventories. Portfolios that take positions based on the futures basis, prior futures excess returns, prior spot returns, or volatility select commodity futures with below normal inventories which our 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 evidence that the position of traders varies with the return of the price-based portfolio strategies—especially momentum. Commercials increase their short positions after price run-up. Noncommercials take larger long positions in commodities with low inventories, high basis, and high momentum.

6. Risk Premiums and the Positions of Traders

Academic researchers have tested the Keynesian Theory of Normal Backwardation by examining the relation between futures returns and "hedging pressure" defined as the relative size of the short positions taken by hedgers. As already mentioned in connection to Tables V–IX, the empirical measure of a commodity's "hedging pressure" used in the literature is the ratio of the net short position collectively taken by "Commercials" to open interest in that commodity available from the CFTC's *Commitments of Traders Reports*. A number of papers have shown that this hedging pressure measure is correlated with futures risk premiums. Most of them document a *contemporaneous* correlation between futures prices and traders'

[21] The signal used in Table IX is the de-meaned value of the volatility during the *next* month over which the corresponding excess return is calculated. If we use as the signal the de-meaned value of its lagged value (i.e., the volatility during the *current* month), the difference in the mean return between High and Low portfolios is much smaller. For example, for the whole sample period, the mean return is 7.42% (rather than 11.47% as in Table IX) for High and 4.64% (rather than 0.65%) for Low portfolios with the t-value of 0.91 (rather than 3.64). The portfolio characteristics, however, are similar to those reported in Panel B of Table IX.

positions.[22] The question we ask in this section is whether hedging pressure at the end of the month is correlated with the *subsequent* futures return from the end of the month to the next.[23]

Table X provides a summary of the net positions of traders for 22 commodities (a subset of the 31 commodities for which the CFTC positions data can be reliably calculated; see Appendix C for details). For each commodity we report the average net position by trader category as percent of open interest, its standard deviation, 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 ("ρ"). The first observation about the table is that Commercials are on average net short in most markets, whereas Noncommercials and Nonreportables positions are on average net long. Exceptions include feeder cattle, lean hogs and milk, where the average position of the Commercials is net long. 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 is large time-series variability in net positions over time: The average standard deviation of the net position of Commercials is 16% per month. Also, there are large cross-sectional differences across commodities. For example, Commercials in oats and platinum are short more than about 95% of the months, whereas the lean hogs and corn Commercials are almost equally likely to be long or short. Nonreportable positions in coffee and soybean meal are almost always net long, whereas Nonreportables in corn are almost always short. Positions are uniformly persistent for all commodities: The first-order autocorrelations of the positions of Commercials range from 0.60 for coffee to 0.88 for milk. It is notable that the Nonreportables are on average net long in most contracts, and most of the time.

[22] Examples include, in addition to those cited in the introduction, Van den Goorbergh (2004) and Szymanowska (2006). Bryant, Bessler, and Haigh (2006) question the hedging pressure hypothesis. De Roon, Nijman, and Veld, (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.

[23] We will not relate the results of this section to the model of Section 2.2 because it is not clear how the model's dichotomy of hedgers versus speculaters corresponds to the CFTC classification. If CFTC "Commercials" consist exclusively of hedgers while "Noncommercials" and "Nonreportables" do not include them, then the model implies that the literature's measure of "hedging pressure" is always 100%. The model would have to include heterogeneous hedgers to make this measure a variable.

Table X. Summary of positions of traders, January1986–October 2011

The table summarizes the positions of traders in commodity futures markets according to the classifications employed in *Commitments of Traders Reports* published by the CFTC: For each category (Commercials, Noncommercials, and Nonreportables), 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 (ρ) of the position. The end of the sample period is October 2011 except for Propane, whose last month of the sample period is May 2000. The first month of the sample period is indicated in the column labeled "Start".

		Net long positions of traders as percent of open interest											
		Commercials				Noncommercials				Nonreportables			
Commodity	Start	Average	St dev	Long (%)	ρ	Average	St dev	Long (%)	ρ	Average	St dev	Long (%)	ρ
Metals													
Copper	198601	−13.1	23.0	31.0	0.80	6.3	17.1	63.5	0.79	6.8	8.8	76.5	0.83
Platinum	198601	−43.6	24.2	5.8	0.75	29.3	23.1	86.8	0.79	14.3	7.3	98.1	0.79
Softs													
Cotton	198601	−6.3	21.9	35.8	0.73	1.2	19.2	56.1	0.76	5.2	5.8	85.8	0.76
Cocoa	198601	−11.0	16.1	25.2	0.80	5.3	13.6	62.9	0.80	5.7	5.4	89.7	0.88
Orange juice	198601	−18.7	25.4	21.6	0.79	10.6	19.1	70.6	0.77	8.1	12.4	85.8	0.86
Lumber	198601	−9.7	19.2	36.1	0.76	4.6	15.4	63.2	0.66	5.1	11.4	66.8	0.74
Coffee	198601	−17.2	14.6	14.5	0.60	8.1	13.4	74.2	0.61	9.2	5.7	96.8	0.85
Grains													
Wheat	198601	−6.3	15.8	41.3	0.77	3.5	12.0	57.4	0.74	2.8	8.7	55.5	0.84
Corn	198601	−1.0	14.0	46.5	0.80	8.0	11.7	72.3	0.79	−7.0	5.5	9.0	0.83
Soybeans	198601	−11.2	16.5	24.8	0.86	9.1	13.0	75.8	0.83	2.1	8.1	55.8	0.91
Soybean oil	198601	−13.0	17.3	27.4	0.74	6.0	12.6	66.5	0.76	7.0	6.9	86.5	0.74
Soybean meal	198601	−16.0	14.9	17.7	0.73	7.4	11.3	72.9	0.77	8.7	5.4	95.2	0.68
Oats	198601	−34.4	17.2	4.5	0.77	12.6	12.0	88.7	0.79	21.8	14.4	94.5	0.86
Live cattle	198601	−7.0	11.3	31.6	0.86	8.8	10.3	78.1	0.76	−1.8	10.2	39.0	0.90
Lean hogs	198601	0.7	11.3	47.1	0.70	5.7	14.1	67.4	0.68	−6.4	7.8	14.5	0.61
Feeder cattle	198601	8.6	11.3	76.8	0.74	10.5	13.3	78.4	0.73	−19.1	13.4	11.6	0.88
Milk	199710	9.4	16.4	69.8	0.88	0.4	12.4	47.3	0.85	−9.8	8.6	11.2	0.80
Energies													
Heating oil	198601	−9.4	9.2	15.8	0.61	2.8	6.3	66.5	0.61	6.5	5.2	91.3	0.74
Crude oil	198601	−1.2	8.2	40.3	0.69	1.3	6.3	59.0	0.71	−0.2	3.1	49.0	0.59
Unleaded gas	198601	−11.4	11.9	19.4	0.67	9.2	9.7	80.6	0.76	2.2	4.1	75.8	0.38
Propane	198708	−9.9	11.8	19.5	0.72	−0.6	6.0	27.9	0.71	10.5	10.3	82.5	0.65
Natural gas	199004	−2.7	11.2	37.5	0.84	−3.1	10.2	43.6	0.86	5.9	3.2	98.5	0.79

Table XI summarizes the results of regressions of futures excess returns from the end of the current month to the end of the next month on hedging pressure. Hedging pressure enters this regression either contemporaneously or predictively: It is for the end of the next month in the left columns

Table XI. Hedging pressure and futures returns, January 1986–September 2010

The table summarizes the results of a simple regression of futures returns from the end of month t to from the end of month $t+1$ on Commercials' positions measured at the end of month $t+1$ (contemporaneous) and measured at the end of month t (lagged). Commercials' 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 *Commitments of Traders Report* published by the CFTC. The table reports the slope coefficient and the associated t-statistic, and the R^2 of the regression. The columns labeled "Start" and "End" indicate the sample period for the contemporaneous regression. The sample size for the lagged regression is less by 1 month.

			Contemporaneous			Lagged		
Commodity	Start	End	Slope	t-stat	R^2	Slope	t-stat	R^2
Metals								
Copper	198601	201109	−0.12	−4.69	0.10	−0.02	−0.75	0.00
Platinum	198601	201109	−0.09	−6.18	0.12	−0.01	−0.39	0.00
Softs								
Cotton	198601	201109	−0.16	−8.24	0.19	−0.03	−1.36	0.01
Cocoa	198601	201109	−0.16	−5.45	0.09	−0.01	−0.31	0.00
Orange juice	199005	201109	−0.12	−5.52	0.10	−0.02	−0.82	0.00
Lumber	198601	201109	−0.11	−4.17	0.05	−0.03	−0.90	0.00
Coffee	198601	201109	−0.31	−7.81	0.17	0.04	0.95	0.00
Grains								
Wheat	198601	201109	−0.15	−5.16	0.09	0.02	0.73	0.00
Corn	198601	201109	−0.22	−7.77	0.16	−0.01	−0.37	0.00
Soybeans	198601	201109	−0.12	−5.51	0.09	0.01	0.26	0.00
Soybean oil	198601	201109	−0.18	−8.58	0.18	−0.01	−0.25	0.00
Soybean meal	198601	201109	−0.21	−8.35	0.17	0.00	−0.15	0.00
Oats	198601	201109	−0.05	−1.41	0.01	0.05	1.50	0.01
Meats								
Live cattle	198601	201109	−0.10	−5.53	0.08	−0.05	−2.47	0.02
Lean hogs	198601	201109	−0.21	−6.29	0.09	−0.01	−0.13	0.00
Feeder cattle	198601	201109	−0.04	−1.73	0.01	0.06	2.80	0.03
Milk	199710	201109	−0.08	−2.83	0.06	−0.06	−2.03	0.03
Energies								
Heating oil	198601	201109	−0.47	−8.37	0.21	−0.04	−0.73	0.00
Crude oil	198601	201109	−0.43	−5.73	0.12	−0.08	−1.05	0.00
Unleaded gas	198601	201109	−0.29	−5.69	0.11	−0.04	−0.86	0.00
Propane	198709	200005	0.10	1.04	0.01	−0.12	−1.23	0.01
Natural gas	199005	201109	−0.46	−5.61	0.12	−0.16	−1.97	0.01

(collectively labeled as "Contemporaneous") and for the end of the current month in right columns (labeled as "Lagged"). 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 the table show that the slope coefficients are generally significantly negative when hedging pressure is measured contemporaneously, but insignificantly different from zero when hedging pressure is lagged. The R^2 of the predictive regressions is on average <1%, compared with 11% on average in the contemporaneous 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. In particular, the significantly negative slope coefficients in the contemporaneous regressions indicate that Commercials increase their short positions as prices go up, whereas Noncommercials increase their long positions in a rising market. This would make Noncommercials appear to be momentum investors. Indeed, the results in Tables VII and VIII, which summarize the characteristics of portfolios sorted on prior futures or prior spot price returns, indicate that Noncommercials take larger long positions in high momentum commodities than in commodities with poor prior performance.

7. Summary and Conclusions

This article examines the relationship between the state of inventories and risk premiums of individual commodity futures, as predicted by our theory, which combines features of the Theory of Storage and the Theory of Normal Backwardation. For this purpose, we collect a comprehensive historical data set of inventories for 31 individual commodities over a 40-year period between 1971 and 2010. Our major findings can be summarized as follows. First, consistent with the predictions of the theory, we empirically document a negative, nonlinear 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, although the positions of participants in futures markets vary with both returns and the state of inventories, we find no evidence that they predict risk premiums on commodity futures.

Appendix A: Construction of the Excess Return and the Basis from Futures Prices

This appendix describes how we constructed the excess return, the basis, the spot price, and monthly volatility from daily data on futures prices.

A.1 SOURCES OF RAW DATA ON DAILY FUTURES PRICES

There are two sources from which daily futures prices, along with the number of days to maturity and the maturity month defining the contract, are obtained. One is the data set provided by Commodity Research Bureau (CRB), which covers all commodity futures traded in North America. The other, for LME, is from Reuters and Bloomberg. For both daily data sets, the last day of observation is October 7, 2011.

From of the universe of CRB commodities, we select those that are traded on major exchanges and that have at least several years of trading history. Those commodities are listed, in the order of the first date of data availability, in Appendix Table A1. Although CRB does not generally provide data on contracts that were discontinued in the past, for some commodities (copper, soy meal, and lean hogs) it combines the old contract and the new contract it replaced to form consistent series, as indicated in the last column of the table. The set of commodities in the table is also the set examined by Gorton and Rouwenhorst (2006) except that the table excludes Electricity (the commodity with no inventories) and that a very recent contract (for gasoline, designated as “RB”) is included in the table here.

Turning to contracts traded on LME, we consider the same set of LME commodities examined by Gorton and Rouwenhorst (2006). They are listed in Appendix Table A2. For the period since July 1993, we use the daily closing prices of the futures contracts expiring on the third Wednesday of each month. For the period before July 1993, there seem no futures prices published by LME. We take the cash price and 3-month forward price for the day and impute the futures prices of hypothetical contracts expiring on the third Wednesday of the current month and the next 2 months (or the next 3 months if the current day is past the third Wednesday of the month). The imputation is done by linearly interpolating between the official LME closing ask prices for cash and 3 month forward.

Table A1. Commodities selected from CRB data set

Source: http://www.crbtrader.com/marketdata/

Commodity name	Exchange	Exchange-designated symbol	Period of daily data availability
Copper	NYMEX/COMEX	HG	July 1959–December 1988 from "Old Copper (CU)" January 1989 to date from "High Grade Copper"
Cotton	ICE (formerly NYBOT)	CT	July 1959 to date
Cocoa	ICE (formerly NYBOT)	CC	July 1959 to date
Wheat	CBOT	W-	July 1959 to date
Corn	CBOT	C-	July 1959 to date
Soybeans	CBOT	S-	July 1959 to date
Soy oil	CBOT	BO	July 1959 to date
Soy meal	CBOT	SM	July 1959–September 1992 (44% protein) October 1992 to date (48% protein)
Oats	CBOT	O-	July 1959 to date
Sugar	ICE (formerly NYBOT)	SB	January 1961 to date
Pork bellies	CME	PB	September 1961 to date
Silver	NYMEX/COMEX	SI	June 1963 to date
Live cattle	CME	LC	November 1964 to date
Lean hogs	CME	LH	February 1966 – December 1996 from "Live Hogs (LG)" February 1997 to date "Lean Hogs"
Orange juice	ICE (formerly NYBOT)	JO	February 1967 to date
Platinum	NYMEX/COMEX	PL	March 1968 to date
Lumber	CME	LB	October 1969 to date
Feeder cattle	CME	FC	November 1971 to date
Coffee	ICE (formerly NYBOT)	KC	August 1972 to date
Gold	NYMEX/COMEX	GC	December 1974 to date
Palladium	NYMEX/COMEX	PA	January 1977 to date
Heat oil	NYMEX/COMEX	HO	November 1978 to date
Crude oil	NYMEX/COMEX	CL	March 1983 to date
Gasoline, unleaded	NYMEX/COMEX	HU	December 1984 to December 2006
Gasoline, blendstock	NYMEX/COMEX	RB	October 2005 to date
Rough rice	CBOT	RR	August 1986 to date
Propane	NYMEX/COMEX	PN	August 1987 to date
Natural gas	NYMEX/COMEX	NG	April 1990 to date
Milk	CME	DE	January 1996 to date
Coal	NYMEX/COMEX	QL	July 2001 to date
Butter	CME	BA	September 2005 to date

Table A2. Commodities from LME

Commodity name	LME symbol	Daily data available since
Zinc	MZN	January 1977
Lead	MPB	February 1977
Nickel	MNI	April 1979
Aluminum	MAL	June 1987
Tin	MSN	July 1989

A.2 MODIFICATIONS MADE ON DAILY DATA

We spent some time looking into the daily data sets and decided to make the following modifications.

LB (lumber). Only for April 8 through 30 of 1982, the daily data set has the futures price (and the number of days to maturity) for contracts maturing in December 1982. We ignore this information about the December 1982 contract by dropping this contract for the indicated period from the data. However, this does not affect our monthly calculations described below.

LC (live cattle). Throughout May 2005, the price of the nearest contract is constant. This contract is dropped from the daily data for the month.

PB (pork bellies). Beginning in August 2010, the data set shows multiple stretches of repeated values for the futures prices. All observations from August 18, 2010 are dropped. The nearest contract in September 1962 and September 1963 are dropped because their prices are constant during those months.

RR (rough rice). The record for October 30, 1987 (the last business day of the month) has information on only one contract and that contract expires before the end of the next month. This means that the excess return from the end of October to the end of November 1987 cannot be calculated (because the investor is assumed to take a position on the same contract during the period). Neither the basis nor the spot price at the end of October can be calculated either (because, as explained below, one needs information on two contracts). For these reasons, we ignore the October 30, 1987 observation and assume that October 29, 1987 (for which we have information on two contracts) is the end of October.

MZN (zinc), MPB (lead), and MNI (nickel). In the LME daily data set we constructed, the futures price is the same across contracts until December

30, 1988 (for MZN and MPB) and until February 1, 1988 (for MNI). Daily data for this period are deleted.

DE (milk). Daily observations before July 16, 1997 are dropped because of prevalence of repeated observations with the same values for many stretches of successive dates. In particular, between April 22, 1997 and July 3, 1997, there is only one contract available and that contract does not change its price during the period.

A.3 MONTHLY VOLATILITY CALCULATED FROM DAILY RETURNS

For the month in question, let t_0 be the last business day of the previous month, t_1 be the last business day of the current month, and F_t be the futures price of the nearest contract on day t of the month. A series of daily futures excess return is calculated as $(F_{t+1} - F_t)/\mathrm{F}_t$ $(t = t_0, t_0 + 1, \ldots, t_1 - 1)$. If the expiration date for F_t differs from that for F_{t+1}, there is a turnover in the nearest contract and we drop the excess return from day t to $t+1$ from the series. Monthly volatility per annum is defined as the square of the average of square of daily excess returns, multiplied by the square root of 365.

A.4 THE MONTHLY FILE

We created a monthly file by extracting, from the two daily data sets just described, the last record of the month for each month. There is one exception: For nine old commodities (HG, CT, CC, W, C, S, BO, SM, and O), their earliest date in the daily data is July 1, 1959. For these commodities, July 1, 1959 is assumed to be the end of June 1959. Each end-of-month record has data on the futures price and the number of days to maturity for at least one contract defined by the month of maturity. The last month in the monthly file is September 2011.

A.5 CALCULATION OF THE BASIS AND THE SPOT PRICE

Let F_{1m} be the futures price at the end of month m on the nearest contract for which data are available and D_{1m} be the number of days to maturity on this contract. Similarly define F_{2m} and D_{2m} for the next nearest contract (if any). The basis at the end of month m, basis$_m$, is defined as

$$\text{basis}_m = 365 \times \left(\frac{F_{1m}}{F_{2m}} - 1\right) / (D_{2m} - D_{1m}).$$

The (theoretical) spot price is an extrapolation by the forward curve to zero, that is,

$$\text{spot\_price}_m = F_{1m} \times \left(1 + \frac{\text{basis}_m}{365} D_{1m}\right).$$

Neither the spot price nor the basis can be calculated for the month if the end-of-month record has information on only one contract. There are 13 such incidents, whose details are the following.

SM (soy meal): 1 case, June 1959. It occurs because the futures price is recorded for only one contract for July 1, 1959 (which is the first date of the daily data and which, as mentioned above, is treated as the end of June 1959).

PB (pork bellies): 5 cases, July–September 1962, July and August 1963. Only one contract is recorded between July 16, 1962 and August 15, 1962 (with August 15 being the last observation for the month of August) and between July 12, 1963 and August 23, 1963 (with August 23 the last observation for the month of August).

PA (palladium): 3 cases, September 2001, June 2002, and December 2002. Only one contract between September 26, 2001 and October 2, 2001, between June 26, 2002 and July 16, 2002, and between December 27, 2002 and January 7, 2003.

RR (rough rice): 1 case, September 1987. Only one contract between September 29 and 30.

PN (propane): 1 case, August 1987. Only one contract between August 21 (the first day of the daily data) and September 16, 1987.

For these 11 cases, for each of the months shown above, we go back to the daily data and see if there are earlier dates for which information from at least two contracts (from which the basis and the spot price can be calculated) are available. Except for SM and PN, there are such dates and we assign to the month the basis and the spot price that can be calculated from the most recent date. For SM, the basis and the spot price for the month in question (June 1959) are taken to be those for July 2, 1959. For PN, the basis for the month in question (August 1987, the first month of the monthly file for PN) is set to zero and therefore the spot price is set to the price of the only available contract for August 31, 1987.

A.6 CALCULATION OF THE EXCESS RETURN

To calculate the excess return from month m to $m + 1$, we first take the nearest contract at the end of month $m + 1$ that has not expired and then turn to the record for month m to find the same contract (i.e., the same expiration month). If the same contract cannot be found for month m, then we go back to month $m + 1$ and take the next nearest contract and then turn to month m to find the same contract. This process is continued until we find the same contract recorded for both month m and month $m + 1$. Usually the contract is the nearest contract at the end of month m whose expiration date is after the end of month $m + 1$, but occasionally the monthly file has no data on that contract. For example, for PL (Platinum), here is the list of contracts whose futures price is available for three successive months December 1979, January 1980, and February 1980:

December 1979:	1/1980, 4/1980, 7/1980, 10/1980, etc.
January 1980:	2/1980, 3/1980, 4/1980, 7/1980, etc.
February 1980:	3/1980, 4, 1980, 7/1980, 10/1980, etc.

Therefore, at the end of December 1979, there are no futures price data for the February and March 1980 contracts. The nearest contract for which the futures price is available for both December 1979 and January 1980 is the April 1980 contract. This happens for HG (6 times), CT (2 times), SB (5), SI (21), LH (1), PL (58), KC (1), GC (3), PA (34), and PN (1).

Let $F_{m,m}$ be the futures price of the contract for month m and $F_{m,m+1}$ be the futures price for month $m + 1$ of the same contract. The double subscript is needed because the contract depends on the two successive months for which the excess return is defined. In the Platinum example above, for $m =$ December 1979 and $m + 1 =$ January 1980, $F_{m,m}$ and $F_{m,m+1}$ are the price at the end of those 2 months of the July 1980 contract; for $m =$ January 1980 and $m + 1 =$ February 1980, the contract on which the excess return is based is the March 1980 contract. With this notation, the excess return from month m to month $m + 1$ is calculated as

$$ER_{m+1} = \frac{F_{m,m+1} - F_{m,m}}{F_{m,m}}.$$

The value is missing if there is no contract in the record for the two successive months. This happens only four times: July–August 1962, August–Sept 1962, July–August 1963, August–Sept 1963 for PB (Pork Bellies). For these 4 months, the value is set to 0.

A.7 COMBINE HU AND RB FOR UNLEADED GAS

For unleaded gas, we combined HU (available until December 2006, see Table I above) and RB (available from October 2005) at April 2006 (so the monthly series is from HU until March 2006 and is from RB since April 2006). The monthly excess return from March to April 2006 is from HU and that from April to May 2006 is from RB.

Appendix B: Inventory Data

This appendix describes the data sources of our inventory data. The Table B1 lists 35 commodities for which we collected inventory data. Of these, inventory data are available only quarterly for sugar, and three times per year (usually February, July, and November) for rough rice. These two commodities are not included in our study because we require monthly inventory data. For feeder cattle, the available inventory series is quarterly (as indicated in the Table B1). We nevertheless include feeder cattle in our study by using the 3-month ahead values of the live cattle inventory for the current monthly level of feeder cattle, under the assumption that it takes 3 months (the average time feeder cattle spends in feedlots) to feed calves to create what are called feeder cattle. As is mentioned in the text, gold and silver are dropped because, although inventory data are daily, we regard these two commodities as essentially financial futures. The monthly inventory series we create is for the end of each month. The value reported in the original source for the beginning of the month is regarded in our analysis as the value at the end of the previous month. If the original series is daily and if the first date is January 2, for example, the January 2 value is treated as the value for the end of the previous month. If the series is weekly, the value in the last week of the month is treated as the end-of-the-month value.

Appendix C: CFTC's Position of Traders

Historical data on the positions of traders published in *Commitments of Traders Reports* by the CFTC can be downloaded from the CFTC's website. We utilize data for 1986–2010 in two Excel files in http://www.cftc.gov/files/dea/history/deafut_xls_1986_2010.zip, and data for 2011 to date in http://www.cftc.gov/files/dea/history/dea_fut_xls_2011.zip. The Report has information (weekly for recent years and monthly or once or twice per month before that) on the long and short positions of the three

Table B1. Inventory data

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
Copper	LME warehouse stocks	LME. Data compiled by Bloomberg: LSCA Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used.	January 2, 1970 to December 2010	Weekly (to May 1990), twice weekly (to April 1997) and daily
Platinum	Comex warehouse stocks	Comex (part of New York Mercantile Exchange (NYMEX)). Data compiled by Bloomberg: NYMXPlat Index	October 31, 1995 to December 2010	Daily
Palladium	NYMEX warehouse stocks	NYMEX (New York Mercantile Exchange). Data compiled by Bloomberg: NYMXPldm Index	October 31, 1995 to December 2010	Daily
Zinc	LME warehouse stocks	LME. Data compiled by Bloomberg: LSZS Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used. Observations missing in January–February 1987 and October–December 1988 and estimated via interpolation.	January 2, 1970 to December 2010	Weekly (to May 1990), twice weekly (to April 1997) and daily
Lead	LME warehouse stocks	LME. Data compiled by Bloomberg: LSPB Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used.	January 2, 1970 to December 2010	Weekly (to May 1990), twice weekly (to April 1997) and daily

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
Nickel	LME warehouse stocks	LME. Data compiled by Bloomberg: LSNI Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used.	July 13, 1979 to December 2010	Weekly (to May 1990), twice weekly (to April 1997) and daily
Aluminum	LME warehouse stocks (High Grade Aluminum)	LME. Data compiled by Bloomberg: LSAH Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used.	December 29, 1978 to December 2010	Weekly (to May 1990), twice weekly (to April 1997) and daily
Tin	LME warehouse stocks	LME. Data compiled by Bloomberg: LSSN Index. For weekly and twice weekly data, the closest available observation to the month-end day is recorded. For daily data, the last day of the month is used. There are gaps in the data from January 1986–June 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 June 30, 1990.	January 2, 1970 to December 2010 (the period for our analysis is since June 30, 1990)	Weekly (to May 1990), twice weekly (to April 1997) and daily
Gold	Comex warehouse stocks	Comex	February 1975 to date	Daily

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
Silver	Comex warehouse stocks	Comex	December 1973 to date	Daily
Cotton	Cotton Historical Certified Stock Report	Intercontinental Exchange (ICE) https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=4	August 23, 2002 to December 2010	Daily
Cocoa	Sum of five series: (1) Visible Stocks of Cocoa in New York warehouses, (2) Same, Philadelphia (Delaware River)warehouses, (3) Same, Port of Hampton Road warehouses, (4) Same, Port of Albany warehouses; and (5) Same, Port of Baltimore warehouses.	ICE. Data to December 2001 is compiled by CRB in CRB Yearbook CDs in millions of bags and rounded to one decimal place. From January 2002, data is directly from ICE https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=4, select "Historical Cocoa Warehouse Stocks: 2002 – Present", uploaded on August 1, 2011	From January 1931 for New York warehouses, January 1958 for Philadelphia warehouses, January 1988 for Port of Hampton Road warehouses, April 2006 for Port of Albany and Port of Baltimore warehouses.	Monthly
Orange juice	"Cold storage stocks of orange juice concentrate in the U.S., millions of pounds"	National Agricultural Statistics Services of U.S. Department of Agriculture (NASS-USDA). Data to December 2004 are compiled by CRB Yearbook CDs and rounded to one decimal place. Data as of the first of the month are shifted to the end of previous month. After that date, the data are taken directly from NASS-USDA monthly Cold Storage reports. Values are missing for May–June 1982, August–September 1982, and	January 1970 to December 2010	Monthly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
		November–December 1982 and are estimated by interpolation.		
Lumber	"Stocks (gross) of softwood lumber in the United States, on the first of the month, in millions of board feet"	American Forest & Paper Association (AFPA). Data compiled by CRB in CRB Yearbook CDs and rounded to one decimal place. Values are missing for June 1998–November 1998, and estimated by linear interpolation. Values for November 2006 and after are not available.	January 1970 to October 2006	Monthly
Coffee	"Certified Coffee 'C' Stocks by Port". Sum of stocks in New York, New Orleans, Houston, Miami, Antwerp, Hamburg / Bremen, and Barcelona.	ICE https://www.theice.com/marketdata/reports/ReportCenter.shtml?reportId=4, select "Historical Coffee 'C' Warehouse Stocks: November 1996 – Present", uploaded on August 1, 2011	December 1996 to December 2010	Monthly
Wheat	From June 25, 1974, "Stocks of Grain at Selected Terminals and Elevator Sites, Thousands of Bushels" (weekly, where the closest available observation to the month-end day is recorded), and from June 1970 to May 1974, "Commercial stocks of domestic wheat in the United States, on the first month, in millions of	The weekly series from Livestock and Seed Division, USDA (U.S. Department of Agriculture). Grain Stocks Report: http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=MarketNewsAndTransportationData&leftNav=MarketNewsAndTransportationData&page=NationalGrainReports, where reports from 1974 to 2005 where obtained on request from USDA The monthly series compiled by CRB in CRB Yearbook CDs.	June 1970 to December 2010	Weekly and monthly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
	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" (monthly, and shifted to the previous month)			
Corn	"Stocks of Grain at Selected Terminals and Elevator Sites, thousands of bushels" (the closest available observation to the month-end day is recorded).	Livestock and Seed Division, USDA Data for 2006 are from http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=MarketNewsAndTransportationData&leftNav=MarketNewsAndTransportationData&page=NationalGrainReports. Prior data were obtained on request from USDA.	June 25, 1974 to December 2010	Weekly
Soybeans	From June 25, 1974 "Stocks of Grain at Selected Terminals and Elevator Sites, Thousands of Bushels" (weekly, where the closest available observation to the	The weekly series from Livestock and Seed Division, USDA. Grain Stocks Report: http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=MarketNewsAndTransportationData&leftNav	December 1961 to December 2010	Weekly and monthly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
	month-end day is recorded), and from December 1961 to May 1974 "Commercial stocks of soybeans in the United States, on the first month, in millions of bushels" (monthly)	=MarketNewsAndTransportation-Data&page=NationalGrainReports, where reports from 1974 to 2005 where obtained on request from USDA The monthly series compiled by CRB in CRB Yearbook CDs.		
Soybean oil	"Stocks of crude soybean oil at factories and warehouses in the United States on the first of month" plus "Stocks of refined soybean oil in the United States on the first of the month, millions of pounds"	USDA. Compiled by CRB in CRB Yearbook CDs. Values are missing for January–February 1991, April–May 1991, July–August 1991 and October–November 1991, and are estimated by linear interpolation.	September 1970 to December 2010 for crude oil,September 1990 to December 2010 for refined oil	Monthly
Soybean meal	"Stocks at oil mills of soybean cake and meal in the United States on the first of the month in thousands of short tons"	USDA. Compiled by CRB in CRB Yearbook CDs. Values are missing for January 1991, March–April 1991, June–July 1991, September–October 1991, and December 1991, and are estimated by linear interpolation.	October 1970 to November 2010	monthly
Oats	"Stocks of Grain at Selected Terminals and Elevator Sites, thousands of bushels" The closest available observation to the	Livestock and Seed Division, USDA Grain Stocks Report Data for 2006 are from http://www.ams.usda.gov/AMSv1.0/ams.fetchTemplateData.do?template=TemplateN&navID=MarketNews	June 25, 1974 to December 2010	Weekly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
	month-end day is recorded.	AndTransportationData&leftNav=MarketNewsAndTransportationData&page=NationalGrainReports. Prior data were obtained on request from USDA.		
Rough rice	“Rice stocks rough and milled”	NASS-USDA	July 1986 to December 2010	February, July, and November.
Sugar	“U.S. sugar stocks held by primary distributors”	Economic Research Services, USDA	January 1990 to December 2010	Quarterly
Pork bellies	From 1970 to December 2004, data from Red Meat Yearbook, “Frozen pork belly stocks in cold storage in the United States, on first of the month, in thousands of pounds” January 2005 – December 2010, data from Cold Storage Report, “Pork Bellies in Cold Storage, at end of month”	Data to December 2004 are compiled in an Excel table by NASS-USDA. Red Meat Yearbook, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1354 After that date, the data are taken directly from NASS-USDA monthly Cold Storage reports. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1034	January 1970 to December 2010	Monthly
Live cattle	From 1970 to December 2004, data from Red Meat Yearbook, “Frozen beef stocks in cold storage in the U.S. on first of the	Data to December 2004 are compiled in an Excel table by NASS-USDA. Red Meat Yearbook, http://usda.mannlib.cornell.	January 1970 to December 2010	Monthly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
	month in thousands of pounds".	edu/MannUsda/viewDocumentInfo.do?documentID=1354		
	January 2005 – December 2010, data from Cold Storage Report, "Total beef in Cold Storage, at end of month"	After that date, the data are taken directly from NASS-USDA monthly Cold Storage reports. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1034		
Lean hogs	From 1970 to December 2004, data from Red Meat Yearbook, "Frozen pork stocks in cold storage in the U.S. on first of the month in thousands of pounds."	Data to December 2004 are compiled in an Excel table by NASS-USDA. Red Meat Yearbook, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1354	January 1970 to December 2010	Monthly
	January 2005–December 2010, data from Cold Storage Report, "Total pork in Cold Storage, at end of month"	After that date, the data are taken directly from NASS-USDA monthly Cold Storage reports. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1034		
Feeder cattle	"United States Cattle Placed on Feed in 7 States"	Economic Research Services, USDA.	January 1974 to December 2010	Quarterly
Milk	"Commercial stocks of milk in the U.S., milk equivalent – milkfat basis"	Data to December 2004 compiled in an Excel table by NASS-USDA (Dairy Yearbook, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1207).	January 1970 to December 2010	Monthly

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
		Afterwards, the data are taken from "Understanding Dairy Markets", University of Wisconsin (http://future.aae.wisc.edu/tab/stocks.html#20).		
		Values are missing for April and May 1982, July and August 1982, and October and November 1982. Those gaps in the series are estimated by linear interpolation.		
Butter	"Commercial stocks of butter in the U.S."	Data to December 2004 are compiled in an Excel table by NASS-USDA.	January 1970 to December 2010	Monthly
		Dairy Yearbook, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1207		
		After that date, the data are taken directly from NASS-USDA monthly Cold Storage reports (calculated as total butter stocks minus government owned).		
		http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1034		
		Values are missing for April and May 1982, July and August 1982, October and November 1982. Those gaps in the series are estimated by linear interpolation. NASS-USDA Excel table data obviously erroneous for February		

(continued)

Table B1. Continued

Commodity name	Definition of the inventory	Source	Period of data availability	Periodicity
		to November 2003, used Cold Storage Reports instead.		
Heating oil	"U.S. total stocks of distillate fuel oil"	Department of Energy (DOE) *Monthly Energy Review* http://www.eia.gov/dnav/pet/pet_stoc_wstk_a_epd0_sae_mbbl_w.htm	January 1945 to December 2010	Monthly
Crude oil	"U.S. ending stocks excluding SPR of crude oil, thousands of barrels"	DOE *Monthly Energy Review* http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MCESTUS1&f=M	January 1920 to December 2010	Monthly
Unleaded gas	"U.S. motor gasoline ending stocks, thousands of barrels"	DOE *Monthly Energy Review* http://www.eia.gov/dnav/pet/pet_stoc_wstk_a_epm0_sae_mbbl_m.htm	January 1945 to December 2010	Monthly
Propane	"U.S. ending Stocks of propane and propylene, thousands of barrels"	DOE *Monthly Energy Review* http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=MPRSTUS1&f=M	January 1971 to December 2010	Monthly
Natural gas	"U.S. total natural gas in underground storage (working gas), millions of cubic feet"	DOE *Monthly Energy Review* http://www.eia.gov/dnav/ng/hist/n5020us2m.htm	September 1975 to December 2010	Monthly
Coal	"U.S. coal stocks, total, in thousand short tons"	DOE *Monthly Energy Review*. http://www.eia.gov/totalenergy/data/monthly/#coal	January 1973 to December 2010	Monthly

groups of traders mentioned in the text ("Commercials", "Noncommercials", and "Nonreportables") as well as the open interest. Here, we describe how we extracted monthly data on those variables from the file mentioned above.

Appendix Table C1 shows how we identified the relevant contract designated by the CFTC for the commodities listed in Table I of the text (except for zinc, lead, nickel, aluminum, and tin, which are traded on the LME and hence not covered by the CFTC Report). The appendix table here also excludes butter because the CFTC Report has the position information only for a handful of months scattered over several subperiods (May–August 1997, April–December 1999, January–May 2000, and May 2006 on) and coal because the CFTC information becomes available only since June 2007.

As is evident from this table, there are nine commodities with two contracts. Of these, five commodities (copper, lean hogs, lumber, unleaded gas, and rough rice) have the two contracts overlapping for several months. If each contract has no gaps (i.e., no missing records within the period covered by the contract), then the positions information is taken from the newer contract as soon as it becomes available (this applies to copper, lumber, and unleaded gas). For lean hogs, the two contracts overlap between April 2, 1996 and December 17, 1996. The newer contract has only one record for April 1996 and the next record is May 14, 1996. So the switch from the older to the newer contract is May 14, 1996 for Lean Hogs. For rough rice, the switch occurs on August 14, 1987 because before then the new contract has only spotty records. For the remaining commodities with two contracts (wheat, corn, soybeans, and oats), the two contracts do not overlap, forming a continuous record.

To create monthly positions series, we selected the last record of the month for each month. If there is only one record for the month that record provides the end-of-month information. Only three commodity-months are for the day of the month that is the 20th or earlier of the month. They are: October 14, 2003, August 3, 2004, and February 20, 2007, all for pork bellies.

The monthly positions series thus created have gaps for four commodities. Pork bellies has no records for August–October 2002, September–October 2004, August 2005, July–December 2006, March–May 2007, July–August 2007, December 2007, February–March 2008, and August 2008 to date. Palladium has no record for August–September 2000, February–June 2001, August 2001 to March 2002, and September 2002. We decided not to use the pork bellies and palladium positions data. Lumber has no records for November 1995 and April 2002. For lumber, we assign the value from the most recent record to those missing months, to create a continuous series for each commodity.

For each commodity, the monthly series ends in October 2011. The first month of the period is shown in Table X of the text.

Appendix D: Details of Estimation Procedures

This appendix is in two parts, describing the procedures for calculating two sorts of statistics employed in the article. The first part is about the t-statistics for scalar time series with serial correlation (shown in Tables V–IX), is fairly standard, but is described here for completeness. 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 III and IV.

D.1 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), we can show that, under the null,

$$\sqrt{n}\bar{y} \underset{d}{\longrightarrow} \mathrm{N}(0, \mathrm{Avar}(\bar{y})),$$

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

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

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

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

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:

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

Table C1. Mapping from CFTC contract code

Commodity Group	Commodity (exchange)	CFTC contract code
Metals	Copper (NYMEX)	85691, 85692
	Platinum (NYMEX)	75651
	Palladium (NYMEX)	76651
Softs	Cotton (NYBOT)	33661
	Cocoa (NYBOT)	73732
	Sugar (NYBOT)	80732
	Orange juice (NYBOT)	40701
	Lumber (CME)	58641, 58643
	Coffee (NYBOT)	83731
Grains	Wheat (CBOT)	1601, 1602
	Corn (CBOT)	2601, 2602
	Soybeans (CBOT)	5601, 5602
	Soybean oil (CBOT)	7601
	Soybean meal (CBOT)	26603
	Oats (CBOT)	4601, 4603
	Rough rice (CBOT)	39601, 39781
Meats	Pork bellies (CME)	56641
	Live cattle (CME)	57642
	Lean hogs (CME)	54641, 54642
	Feeder cattle (CME)	61641
	Milk (CME)	52641
Energies	Heating oil (NYMEX)	22651
	Crude oil (NYMEX)	67651
	Unleaded gas (NYMEX)	111652, 111659
	Propane (NYMEX)	66651
	Natural gas (NYMEX)	23651

This is the t-statistics displayed in Tables V–IX. In those tables, the window width q is 12 (months).

D.2 CALCULATING STANDARD ERRORS OF POOLED OLS ESTIMATES

The system of equations estimated in Tables III and IV can be written as

$$y_{mt} = z'_{mt}\delta + \varepsilon_{mt} \quad (m = 1, 2, \ldots, M; t = 1, 2, \ldots, n) \tag{A.1}$$

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 III, 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

$$\underset{(L\times 1)}{\hat{\delta}} = \left[\sum_{m=1}^{M}\left(\sum_{t=1}^{n} z_{mt}z'_{mt}\right)\right]^{-1}\sum_{m=1}^{M}\left(\sum_{t=1}^{n} z_{mt}y_{mt}\right)$$
$$= \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt}z'_{mt}\right)\right]^{-1}\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt}y_{mt}\right) \tag{A.2}$$

Substituting (A.1) into (A.2), we obtain

$$\sqrt{n}(\hat{\delta}-\delta) = \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt}z'_{mt}\right)\right]^{-1}\sum_{m=1}^{M}\left(\frac{1}{\sqrt{n}}\sum_{t=1}^{n} z_{mt}\varepsilon_{mt}\right)$$
$$= \left[\sum_{m=1}^{M}\left(\frac{1}{n}\sum_{t=1}^{n} z_{mt}z'_{mt}\right)\right]^{-1} F'\left(\frac{1}{\sqrt{n}}\sum_{t=1}^{n} g_t\right) \tag{A.3}$$

where

$$\underset{(ML\times L)}{F} \equiv \begin{bmatrix} I_L \\ I_L \\ \vdots \\ I_L \end{bmatrix}, \quad \underset{(ML\times 1)}{g_t} = \begin{bmatrix} z_{1t}\varepsilon_{1t} \\ z_{2t}\varepsilon_{2t} \\ \vdots \\ z_{Mt}\varepsilon_{Mt} \end{bmatrix}. \tag{A.4}$$

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

$$\underset{(L\times L)}{\text{Avar}(\hat{\delta})} = \left[\text{E}\left(z_{mt}z'_{mt}\right)\right]^{-1} F' \underset{(ML\times ML)}{\text{Avar}(\bar{g})}\, F\left[\text{E}\left(z_{mt}z'_{mt}\right)\right]^{-1}, \tag{A.5}$$

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:

$$\underset{(ML\times ML)}{\text{Avar}(\bar{g})} = \sum_{j=-\infty}^{\infty}\Gamma_j = \Gamma_0 + \sum_{j=1}^{\infty}\left(\Gamma_j + \Gamma'_j\right), \tag{A.6}$$

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

$$\Gamma_j \equiv \text{E}\left(g_t g'_{t-j}\right)(j = 0, \pm 1, \pm 2, \ldots). \tag{A.7}$$

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

$$\underset{(ML\times ML)}{\Gamma_j} = \begin{bmatrix} \mathrm{E}(\varepsilon_{1t}\varepsilon_{1,t-j}z_{1t}z'_{1,t-j}) & \mathrm{E}(\varepsilon_{1t}\varepsilon_{2,t-j}z_{1t}z'_{2,t-j}) & \cdots & \mathrm{E}(\varepsilon_{1t}\varepsilon_{n,t-j}z_{1t}z'_{M,t-j}) \\ \mathrm{E}(\varepsilon_{2t}\varepsilon_{1,t-j}z_{2t}z'_{1,t-j}) & \mathrm{E}(\varepsilon_{2t}\varepsilon_{2,t-j}z_{2t}z'_{2,t-j}) & \cdots & \mathrm{E}(\varepsilon_{2t}\varepsilon_{M,t-j}z_{2t}z'_{M,t-j}) \\ \vdots & \cdots & \cdots & \vdots \\ \mathrm{E}(\varepsilon_{Mt}\varepsilon_{1,t-j}z_{Mt}z'_{1,t-j}) & \mathrm{E}(\varepsilon_{Mt}\varepsilon_{2,t-j}z_{Mt}z'_{2,t-j}) & \cdots & \mathrm{E}(\varepsilon_{Mt}\varepsilon_{M,t-j}z_{Mt}z'_{M,t-j}) \end{bmatrix}$$
$$= \left(\mathrm{E}(\varepsilon_{mt}\varepsilon_{h,t-j}z_{mt}z'_{h,t-j})\right)_{m,h} \tag{A.8}$$

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

The Newey–West estimator of $\mathrm{Avar}(\bar{g})$ is

$$\underset{(ML\times ML)}{\mathrm{Est.Avar}(\bar{g})} \equiv \sum_{j=-q}^{q}\left(1-\left|\frac{j}{q+1}\right|\right)\hat{\Gamma}_j, \tag{A.9}$$

where $\hat{\Gamma}_j$ is a consistent estimate of Γ_j to be specified below. The parameter q in (A.9) is sometimes called the *bandwidth*. With $\mathrm{Avar}(\bar{g})$ thus estimated, we can estimate $\mathrm{Avar}(\hat{\delta})$ as

$$\underset{(L\times L)}{\mathrm{Est.Avar}(\hat{\delta})} = \left[\sum_{m=1}^{M}\frac{1}{n}\sum_{t=1}^{n} z_{mt}z'_{mt}\right]^{-1} F' \underset{(ML\times ML)}{\mathrm{Est.Avar}(\bar{g})}\, F\left[\sum_{m=1}^{M}\frac{1}{n}\sum_{t=1}^{n} z_{mt}z'_{mt}\right]^{-1}. \tag{A.10}$$

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 $\mathrm{Est.Avar}(\hat{\delta})$, we need to estimate values of $\widehat{\Gamma}_j$, which are $ML \times ML$ matrixes of fourth moments. For the case of the Metals group in Table III, 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 $\mathrm{E}(\varepsilon_{mt}\varepsilon_{h,t-j}|z_{mt}, z_{h,t-j}) = \mathrm{E}(\varepsilon_{mt}\varepsilon_{h,t-j})$). Under conditional homoskedasticity, we can write Γ_j in (A.8) as products of second moments:

$$\underset{(ML\times ML)}{\Gamma_j} = \left(\mathrm{E}\left(\varepsilon_{mt}\varepsilon_{h,t-j}\right)\mathrm{E}\left(z_{mt}z_{h,t-j}\right)\right)_{m,h}. \tag{A.11}$$

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

$$\underset{(ML\times ML)}{\widehat{\Gamma}_j} = \left(\frac{1}{n}\sum_{t=1}^{n}\widehat{\varepsilon}_{mt}\widehat{\varepsilon}_{h,\,t-j}\frac{1}{n}\sum_{t=1}^{n}z_{mt}z_{h,\,t-j}\right)_{m,\,h}, \tag{A.12}$$

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

$$\widehat{\varepsilon}_{mt} \equiv y_{mt} - z'_{mt}\widehat{\delta}.$$

To recapitulate, for balanced panels, the pooled OLS point estimate is (A.2) and its asymptotic variance Est.Avar($\hat{\delta}$) is estimated by (A.10) with Est.Avar($\bar{g}$) given by (A.9) and (A.12).

We now turn to our treatment of missing observations. In the case of Tables III and IV, the period from which (y_{mt}, z_{mt}) is observable depends on m. That is, (y_{mt}, z_{mt}) is observable only for $t = s(m), s(m)+1, \ldots, n$, 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:

$$\underset{(L\times 1)}{\widehat{\delta}} = \left[\sum_{m=1}^{M}\left(\sum_{t=s(m)}^{n} z_{mt}z'_{mt}\right)\right]^{-1}\sum_{m=1}^{M}\left(\sum_{t=s(m)}^{n} z_{mt}y_{mt}\right). \tag{A.2$'$}$$

The expression for Est.Avar($\hat{\delta}$) is similarly modified so that the averages over t are averages over available terms. Thus, (A.10) becomes

$$\begin{aligned}\underset{(L\times L)}{\text{Est.Avar}(\hat{\delta})} =& \left[\sum_{m=1}^{M}\frac{1}{n-s(m)+1}\sum_{t=s(m)}^{n} z_{mt}z'_{mt}\right]^{-1} \\ & F' \underset{(ML\times ML)}{\text{Est.Avar}(\bar{g})}\, F\left[\sum_{m=1}^{M}\frac{1}{n-s(m)+1}\sum_{t=s(m)}^{n} z_{mt}z'_{mt}\right]^{-1}\end{aligned} \tag{A.10$'$}$$

and (A.12) becomes

$$\begin{aligned}\underset{(ML\times ML)}{\widehat{\Gamma}_j} =& \left(\frac{1}{n-N(m,h,j)+1}\sum_{t=N(m,h,j)}^{n}\widehat{\varepsilon}_{mt}\widehat{\varepsilon}_{h,\,t-j}\frac{1}{n-N(m,h,j)+1}\right. \\ & \left.\sum_{t=N(m,h,j)}^{n} z_{mt}z_{h,\,t-j}\right)_{m,\,h}\end{aligned} \tag{A.12$'$}$$

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

References

Acharya, V., Lochstoer, L., and Ramadorai, T. (2010) Limits to arbitrage and hedging: Evidence from commodity markets. Unpublished working paper, New York University, Columbia Business School, University of Oxford.

Bessembinder, H. (1992) Systematic risk, hedging pressure, and risk premiums in futures markets, *Review of Financial Studies* **5**, 637–667.

Bodie, Z. and Rosansky, V. (1980) Risk and return in commodity futures, *Financial Analysts Journal* **36**, 27–39.

Brennan, M. (1991) The price of convenience and the valuation of commodity contingent claims, in: D. Lund and B. Oksendal (eds), *Stochastic Models and Option Values*, Emerald Group Publishing, North Holland (Amsterdam).

Brennan, M. (1958) The supply of storage, *American Economic Review* **48**, 50–72.

Brennan, M. and Schwartz, E. (1985) Evaluating natural resource investments, *Journal of Business* **58**, 135–157.

Bresnahan, T. and Spiller, P. (1986) Futures market backwardation under risk neutrality, *Economic Inquiry* **24**, 429–441.

Bryant, H., Bessler, D., and Haigh, M. (2006) Causality in future markets, *Journal of Futures Markets* **26**, 1039–1057.

Carbonez, K., Nguyen, V., and Sercu, P. (2009) Do inventories really yield a convenience? An empirical analysis of the risk-adjusted spread. Unpublished working paper, Katholieke Universiteit Leuven.

Carter, C., Rausser, G., and Schmitz, A. (1983) Efficient asset portfolios and the theory of normal backwardation, *Journal of Political Economy* **91**, 319–331.

Chang, E. (1985) Returns to speculators and the theory of normal backwardation, *Journal of Finance* **40**, 193–208.

De Roon, F., Nijman, T., and Veld, C. (2000) Hedging pressure effects in futures markets, *Journal of Finance* **55**, 1437–1456.

Deaton, A. and Laroque, G. (1992) On the behavior of commodity prices, *Review of Economic Studies* **59**, 1–23.

Dusak, K. (1973) Futures trading and investor returns: An investigation of commodity market risk premiums, *Journal of Political Economy* **81**, 1387–1406.

Dhume, D. (2010) Using durable consumption risk to explain commodity returns. Unpublished working paper, Harvard University.

Dincerler, C., Khokher, Z., and Simin, T. (2005) An empirical analysis of commodity convenience yields. Unpublished working paper, McKinsey & Co. Inc., University of Western Ontario, Pennsylvania State University.

Ederington, L. and Lee, J. (2001) Who trades futures and how: Evidence from the heating oil futures market, *Journal of Business* **75**, 353–373.

Erb, C. and Harvey, C. (2006) The strategic and tactical value of commodity futures, *Financial Analysts Journal* **62**, 69–97.

Etula, E. (2010) Broker-dealer risk appetite and commodity returns. Federal Reserve Bank of New York Staff Report, no. 406.

Evans, L. and Guthrie, G. (2008) Commodity price behavior with storage frictions. Unpublished working paper, Victoria University of Wellington.

Fama, E. and French, K. (1988) Business cycles and the behavior of metals prices, *Journal of Finance* **43**, 1075–1093.

Fama, E. and French, K. (1987) Commodity futures prices: Some evidence on forecast power, premiums, and the theory of storage, *Journal of Business* **60**, 55–73.

Gorton, G. and Rouwenhorst, K. (2005) A note on Erb and Harvey (2005). Unpublished working paper, Yale School of Management.

Gorton, G. and Rouwenhorst, K. (2006) Facts and fantasies about commodity futures, *Financial Analysts Journal* **62**, 47–68.

Green, P. and Silverman, B. (1994) *Nonparametric Regression and Generalized Linear Models*, Chapman & Hall/CRC Press, Boca Raton, Florida.

Hayashi, F. (2000) *Econometrics*, Princeton University Press, Princeton, New Jersey.

Heinkel, R., Howe, M., and Hughes, J. (1990) Commodity convenience yields as an option profit, *Journal of Futures Markets* **10**, 519–533.

Hicks, J. R. (1939) *Value and Capital*, Oxford University Press, Cambridge, UK.

Hirshleifer, D. (1990) Hedging pressure and futures price movements in a general equilibrium model, *Econometrica* **58**, 411–428.

Hirshleifer, D. (1988) Residual risk, trading costs and commodity futures risk premia, *Review of Financial Studies* **1**, 173–193.

Hong, H. and Yogo, M. (2012) What does futures market interest tell us about the macroeconomy and asset prices? *Journal of Financial Economics* **105**, 473–490.

Jaganathan, R. (1985) An investigation of commodity futures prices using the consumption-based intertemporal capital asset pricing model, *Journal of Finance* **40**, 175–191.

Kaldor, N. (1939) Speculation and economic stability, *Review of Economic Studies* **7**, 1–27.

Keynes, J. (1930) *A Treatise on Money*, **Vol. 2**, Macmillan, London.

Khan, S., Khokher, Z., and Simin, T. (2008) Expected commodity futures returns. Unpublished working paper, University of Western Ontario, Pennsylvania State University.

Kolb, R. (1992) Is normal backwardation normal?, *Journal of Futures Markets* **12**, 75–91.

Litzenberger, R. and Rabinowitz, N. (1995) Backwardation in oil futures markets: Theory and empirical evidence, *Journal of Finance* **50**, 1517–1545.

Mayers, D. (1972) Non-marketable assets and capital market equilibrium under uncertainty, in: M. Jensen (ed.), *Studies in the Theory of Capital Markets*, Praeger, New York City, New York.

Miffre, J. and Rallis, G. (2007) Momentum in commodity futures markets, *Journal of Banking and Finance* **31**, 1863–1886.

Ng, V. and Pirrong, S. (1994) Fundamentals and volatility: Storage, spreads, and the dynamics of metals prices, *Journal of Business* **67**, 203–230.

Pindyck, R. (1994) Inventories and the short-run dynamics of commodity prices, *RAND Journal of Economics* **25**, 141–159.

Pirrong, C. (2005) Momentum in futures markets. Unpublished working paper, University of Houston.

Routledge, B., Seppi, D., and Spatt, C. (2000) Equilibrium forward curves for commodities, *Journal of Finance* **55**, 1297–1338.

Schwartz, E. (1997) The stochastic behavior of commodity prices: Implications for valuation and hedging, *Journal of Finance* **52**, 923–973.

Shen, Q., Szakmary, A., and Sharma, S. (2007) An examination of momentum strategies in commodity futures markets, *Journal of Futures Markets* **26**, 227–256.

Stoll, H. (1979) Commodity futures and spot price determination and hedging in capital market equilibrium, *Journal of Financial and Quantitative Analysis* **14**, 873–894.

Szymanowska, M. (2006) Essays on rational asset pricing, PhD dissertation, Tilburg University.

Szymanowska, M., de Roon, F., Nijman, T., and van den Goorbergh, R. (2011) An anatomy of commodity futures risk premia. Unpublished working paper, Erasmus University Rotterdam, Tilburg University.

Turnovsky, S. (1983) The determination of spot and futures prices with storable commodities, *Econometrica* **51**, 1363–1387.

Van den Goorbergh, R. (2004) Essays on optimal hedging, and investment strategies, and on derivative pricing, PhD dissertation, Tilburg University.

Working, H. (1949) The theory of the price of storage, *American Economic Review* **39**, 1254–1262.

Yogo, M. (2006) A consumption-based explanation of expected stock returns, *Journal of Finance* **61**, 539–580.