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Commodity Futures Prices: Some Evidence on Forecast Power, Premiums, and the Theory of Storage*

We examine two models of commodity futures prices. The theory of storage explains the difference between contemporaneous futures and spot prices (the basis) in terms of interest changes, warehousing costs, and convenience yields. We find evidence of variation in the basis in response to both interest rates and seasonals in convenience yields. The second model splits a futures price into an expected premium and a forecast of the maturity spot price. We find evidence of forecast power for 10 of 21 commodities and time-varying expected premiums for five commodities.

I. Introduction

There are two popular views of commodity futures prices. The theory of storage of Kaldor (1939), Working (1948), Brennan (1958), and Telser (1958) explains the difference between contemporaneous spot and futures prices in terms of interest forgone in storing a commodity, warehousing costs, and a convenience yield on inventory. The alternative view splits a futures price into an expected risk premium and a forecast of a future spot price. See, for example, Cootner (1960), Dusak (1973), Breeden (1980), and Hazuka (1984).

The theory of storage is not controversial. In contrast, there is little agreement on whether futures prices contain expected premiums or have power to forecast spot prices. We use both models to study the behavior of futures prices for 21 commodities. We find that more powerful statistical tests make the response of futures prices to storage-cost variables easier to detect than evidence that futures prices contain premiums or power to forecast spot prices.

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II. The Basis: Evidence on the Theory of Storage

A. The Theory of Storage

Let $F(t, T)$ be the futures price at time t for delivery of a commodity at T. Let $S(t)$ be the spot price at t. The theory of storage predicts that the return from purchasing the commodity at t and selling it for delivery at T, $F(t, T) - S(t)$, equals the interest forgone, $S(t)R(t, T)$, plus the marginal storage cost, $W(t, T)$, less the marginal convenience yield from an additional unit of inventory, $C(t, T)$:

$$F(t, T) - S(t) = S(t)R(t, T) + W(t, T) - C(t, T). \tag{1}$$

Equivalently,

$$[F(t, T) - S(t)]/S(t) = R(t, T) + [W(t, T) - C(t, T)]/S(t). \tag{2}$$

We call $F(t, T) - S(t)$, or $[F(t, T) - S(t)]/S(t)$, the basis.

The marginal convenience yield, $C(t, T)$, arises because inventory can have productive value. For example, there may be a convenience yield from holding inventories of some commodities (such as wheat) because they are inputs to the production of other commodities (such as flour). Or there may be a convenience yield from holding inventories to meet unexpected demand.

The theory of storage predicts a negative relation between convenience yields and inventories. Brennan (1958) and Telser (1958) provide detailed studies of the relations between convenience yields and inventories for several agricultural commodities. Since good inventory data are not available for many of the commodities studied here, we take a cruder approach. Seasonals in production or demand can generate seasonals in inventories. Under the theory of storage, inventory seasonals generate seasonals in the marginal convenience yield and in the basis. We test for seasonals in the basis.

Another implication of (2) is that, controlling for variation in the marginal storage cost and the marginal convenience yield, the $T - t$ period basis for any stored commodity should vary one-for-one with the $T - t$ period interest rate. We provide (apparently the first) systematic tests of this well-known implication of the theory of storage.

B. Data

We construct monthly observations on the basis $[F(t, T) - S(t)]/S(t)$ and the interest rate $R(t, T)$ for 1-, 3-, 6-, and 12-month maturities ($T - t$). The interest rates are beginning-of-month yields on Treasury bills calculated from the quotes in various issues of Salomon Brothers' *Analytical Record of Yields and Yield Spreads*. The sample period for interest rates is January 1967–May 1984.

Measuring the basis presents two problems. The first is that most futures contracts do not have a specific maturity. Instead, there is a

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delivery period of 3–4 weeks at the beginning of the maturity month. We assume that contracts mature on the first trading day of the delivery month. This means, for example, that the April 1, 1980, futures price for the May 1980 wheat contract is used as a 1-month futures price.

The second complication is that good spot-price data are not available for most commodities. We use futures prices on maturing contracts to measure spot prices. For example, the spot price for wheat on March 1 is the futures price for the contract that matures in March. Since futures contracts do not mature each month, this solution limits sample sizes. The number of observations on the basis is always less than the number of months in the sample period. On the other hand, using maturing futures prices to measure spot prices ensures that spot and futures prices are for the same commodity and are sampled at the same time.

Table 1 summarizes the structure of the commodity-price data. Each row shows the sample period for a commodity and the standard months in which contracts mature. Contracts for these standard months usually begin trading between 8 and 12 months before maturity, and they are traded every year. Copper, gold, and silver have supplemental contracts that fill in the months between the standard contracts. These supplemental contracts usually begin trading 3 or 4 months before maturity. They are useful because they augment the spot-price series.

C. *Standard Deviations of the Basis*

The second column of table 2 shows standard deviations of the 6-month basis for the 21 commodities. The 6-month maturity is chosen since it is available for all commodities but cotton. The 3-month basis is used for cotton. Basis standard deviations differ systematically across commodity groups. The precious metals have the lowest standard deviations—2.0% for gold, 1.5% for silver, and 4.2% for platinum. The standard deviations for the agricultural products range from 4.6% for corn to 9.7% for oats. The animal products have the largest basis standard deviations. The standard deviation for cattle is 5.6%, and the standard deviations for the other four animal products range from 10.1% for broilers to 22.2% for eggs.

The differences in the basis standard deviations for commodity subgroups are consistent with the theory of storage. One source of variation in the basis is seasonals in supply and demand. For example, spot prices for agricultural commodities usually increase between harvests and fall across harvests. Because of this pattern in the spot price, the basis is usually positive when the futures contract matures in the current crop year and negative when the futures contract matures early in the next crop year. Storage costs are important in determining the magnitude of the seasonal variation in spot prices. Higher storage costs

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TABLE 1 **Layout of Commodity Futures Data**

Commodity	Exchange*	Sample Period	Standard Delivery Months											
			Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Agricultural products:														
Cocoa	CSCE	3/66–7/84			√		√		√		√			√
Coffee	CSCE	9/72–7/84			√		√		√		√			√
Corn	CBT	3/66–7/84			√		√		√		√			√
Cotton	CTN	3/67–7/84			√		√		√			√		√
Oats	CBT	5/66–7/84			√		√		√		√			√
Orange juice	CTN	2/67–7/84	√		√		√		√		√		√	
Soybeans	CBT	3/66–7/84	√		√		√		√	√	√		√	
Soy meal	CBT	5/66–7/84	√		√		√		√	√	√	√		√
Soy oil	CBT	5/66–7/84	√		√		√		√	√	√	√		√
Wheat	CBT	5/66–7/84			√		√		√		√			√
Wood products:														
Lumber	CME	1/70–12/82	√		√		√		√		√		√	
Plywood	CBT	1/70–9/83	√		√		√		√		√		√	
Animal products:														
Broilers†	CBT	8/68–6/81	√		√		√	√	√	√	√		√	
Eggs†	CME	5/66–12/80	√	√	√	√	√	√	√		√	√	√	√
Cattle	CME	1/72–7/84	√		√	√	√			√	√	√	√	
Hogs	CME	3/66–7/84		√		√		√	√	√		√		√
Pork bellies	CME	5/66–7/84		√	√		√		√	√				
Metals:‡														
Copper	Comex	3/66–7/84	√		√		√		√		√			√
Gold	Comex	2/75–7/84		√		√		√		√		√		√
Platinum	NYM	1/68–7/84	√			√			√			√		
Silver	Comex	1/67–7/84	√		√		√		√		√			√

* CBT = Chicago Board of Trade; CME = Chicago Mercantile Exchange; Comex = Commodity Exchange; CSCE = Coffee, Sugar, and Cocoa Exchange; CTN = New York Cotton Exchange; NYM = New York Mercantile Exchange.

† The standard delivery months for broilers and eggs change toward the end of the sample period. The delivery months prevailing over most of the period are indicated here.

‡ Supplemental contracts are traded on copper, gold, and silver. These contracts fill in the months between the standard contracts.

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TABLE 2 **Regressions of the 6-Month Basis on the 6-Month Interest Rate and Monthly Seasonal Dummies:**

$$\frac{F(t, T) - S(t)}{S(t)} = \sum_{m=1}^{12} \alpha_m d_m + \beta R(t, T) + e(t, T)$$

Commodity	Obs.	SD	β	$s(\beta)$	F	df	R_1^2	R_2^2	Storage (%)	Handling (%)
Agricultural products:										
Cocoa	35	8.1	1.16	1.44	.00	1	.00	.03	.16	.35
Coffee	30	9.6	.29	1.57	1.72	4	.06	.03	.12	.26
Corn	35	4.6	.86	.52	.01	1	.05	.07	1.41	1.73
Cotton	36	4.9	.84	1.46	1.14	2	−.02	−.02	.32	.13
Oats	34	9.7	1.06	1.27	6.55	1	.16	.01	2.65	3.26
Orange juice	102	9.2	1.39	1.21	3.32	5	.14	.04	.30	.32
Soybeans	105	7.8	1.88	.71	5.72	5	.30	.14	.64	.78
Soy meal	70	7.2	2.03	.84	.20	5	.16	.21	...	...
Soy oil	74	8.9	1.73	1.28	.79	5	.06	.07	.27	.30
Wheat	35	6.8	1.05	.86	9.03	1	.24	.05	1.39	1.71
Wood products:										
Lumber	86	13.6	2.41	2.21	1.86	5	.12	.07	1.96	3.82
Plywood	82	7.4	1.23	1.17	.71	5	.04	.06	...	...
Animal products:										
Broilers	64	10.1	1.39	1.65	5.43	11	.44	.00	...	...
Cattle	70	5.6	−.06	.57	4.48	5	.19	−.01	...	...
Eggs	80	22.2	−4.32	3.34	4.96	11	.38	.04	...	...
Hogs	102	10.9	2.21	1.36	1.79	9	.14	.08	...	...
Pork bellies	34	14.3	2.71	1.66	5.86	1	.19	.07	.98	2.54
Metals:										
Copper	89	6.5	1.39	.85	1.05	5	.14	.13	.12	.49
Gold	57	2.0	1.07	.13	.29	6	.81	.83	.01	.03
Platinum	66	4.2	1.18	.63	.28	3	.15	.18	.01	.01
Silver	101	1.5	.77	.16	.31	5	.58	.60	.03	.06

NOTE.—Obs. is the number of observations. SD is the standard deviation of the 6-month basis. df is the numerator degrees of freedom for the F-statistic test of the hypothesis that all the seasonal dummies in a regression are equal. R_2^2 is the coefficient of determination in the simple regression of the basis on the interest rate, and R_1^2 is for the regression that includes the seasonal dummies. Storage is the monthly warehousing cost per dollar of the June 1984 spot price. Handling is the total cost of loading and unloading the commodity at the warehouse per dollar of the June 1984 spot price. Storage and handling charges are from futures exchanges, dealers, elevators, and warehouses. These charges are reported only for commodities that have standard storage arrangements. The absence of such arrangements implies high storage costs. The 6-month maturity is not available for cotton. The 3-month maturity is used.

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imply larger expected spot-price changes to induce storage between harvests. Thus seasonal variation in the basis should be an increasing function of storage costs.

Demand and supply shocks also generate variation in the basis. The effect of shocks on the basis depends to a large extent on the way inventories adjust to transmit the price effects of shocks through time. For example, suppose there is a spell of propitious weather before a harvest that raises expected future supplies and lowers expected future prices. The expected decline in the spot price is partly offset by the inventory response it generates. The gap between current and expected future prices is narrowed as more inventory is sold immediately. Higher inventory levels allow larger inventory responses to demand and supply shocks and thus lower variation in expected price changes. Since storage costs deter storage, the effect of demand and supply shocks on the variability of the basis should be an increasing function of storage costs. See French (1986).

The analysis predicts high basis standard deviations for seasonal, high-storage-cost commodities. Metal storage costs (table 2) are low relative to value, and the metals are not subject to seasonals in supply or demand. Thus the low basis standard deviations for the metals are consistent with the theory of storage. It is also consistent with the theory of storage that the highest basis standard deviations are observed for some of the wood and animal products (lumber, broilers, eggs, hogs, and pork bellies), where bulk and perishability make storage expensive.

D. *Regression Tests*

To obtain more direct tests of the theory of storage, we regress the basis against the nominal interest rate and monthly seasonal dummies:

$$\frac{F(t, T) - S(t)}{S(t)} = \sum_{m=1}^{12} \alpha_m d_m + \beta R(t, T) + e(t, T), \tag{3}$$

where d_m equals 1.0 if the futures contract matures in month m and 0.0 otherwise. The hypothesis of the storage equation (2) is that the slope β should be 1.0 for any commodity continuously stored; that is, the basis should vary one for one with the nominal interest rate. The seasonal dummies in (3) are a crude way to capture variation in the marginal convenience yield in (2), which is due to seasonals in production or demand.

1. *Interest-rate relations.* Estimates of the slopes in regression (3) are in table 2. The metals produce the strongest evidence of variation in the basis that tracks interest rates, and gold produces the strongest evidence among the metals. The interest-rate coefficient in the 6-month gold regression is 1.07. The estimates for 1, 3, and 12 months to matu-

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rity (not reported) range from 0.99 to 1.06. Table 2 shows coefficients of determination (R^2) for simple regressions of the basis on the nominal interest rate as well as for the regressions that include seasonal dummies. Nominal interest rates alone explain 83% of the 6-month basis variance for gold. The nominal interest rate explains 60% of the variance of the 6-month basis for silver. Explanatory power is lower for platinum and lower again for copper, but estimated interest rate coefficients are close to 1.0. The metals regressions for 1, 3, and 12 months to maturity (not shown) are similar. Metals prices are consistent with the hypothesis that the basis tracks nominal interest rates.

The regressions for the agricultural and wood products are also consistent with the hypothesis that the basis varies one for one with the nominal interest rate. All the interest-rate coefficients are positive, many are close to 1.0, and only two are more than 1.0 standard error from 1.0. However, the standard errors of the interest-rate coefficients for the agricultural and wood products are all greater than 0.5. This lack of precision means that the regression slopes cannot provide convincing evidence of one-for-one variation in the basis in response to nominal interest rates. The interest-rate coefficients for the animal-product regressions are even less precise. The standard errors of the coefficients are typically greater than 1.0, and the estimates are consistent with a wide range of values for the true slopes, including 0.0 as well as 1.0.

Restated in terms of (2), the regressions indicate that variation in the interest rate is a large fraction of basis variation for gold and silver. For other commodities, there is suggestive evidence of basis variation in response to the nominal interest rate, but variation in the $[W(t, T) - C(t, T)]/S(t)$ component of the basis leads to imprecise estimates of the relation between the basis and the interest rate. For agricultural, wood, and animal products, basis variation must be explained primarily in terms of economic conditions that generate variation in marginal storage costs, $W(t, T)$, and marginal convenience yields, $C(t, T)$, rather than in terms of the role of the interest rate in the storage process.

2. *Seasonals in the basis.* The seasonal dummies in (3) are evidence about seasonal variation in the basis. The F-statistics testing the hypothesis that all seasonal coefficients in a regression are equal never indicate reliable seasonals in the basis for any metal. This is not surprising since there is no presumption of seasonals in the demand or supply of metals.

As expected, there are reliable seasonals in the basis for many of the seasonally produced agricultural commodities, including corn, oats, orange juice, soybeans, and wheat. (Although the 6-month basis for corn in table 2 does not show seasonals, there are reliable seasonals in the 3-month basis.) On the other hand, it is a bit unexpected that five agricultural commodities—cocoa, coffee, cotton, soy meal, and soy

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oil—produce no reliable evidence of seasonals in the 6-month basis. The absence of seasonals for soy meal and soy oil is interesting given the strong seasonals in the basis for soybeans. Apparently, the production process for meal and oil reduces the effect of seasonals in the price of soybeans.

The animal products produce the strongest evidence of seasonals in the basis. The coefficients of determination in the seasonal regressions for broilers, cattle, eggs, and pork bellies are at least 0.19. The seasonals in the 6-month basis for hogs are weaker, but the coefficients of determination in the 1- and 3-month seasonal regressions for hogs (not shown) are 0.47 and 0.72, respectively. Since the nominal interest rate explains only a small fraction of the basis variation for the animal products, much of their basis variation can be attributed to seasonals.

Since the animal products are subject to seasonals in production and sometimes in demand (see Bessant 1982), and since bulk and perishability imply storage costs that are high relative to value, strong seasonals in the basis confirm the predictions of the theory of storage. On the other hand, lumber and plywood also have high storage costs and seasonals in demand due to seasonals in building activity, but the regressions for lumber and plywood produce no reliable evidence of seasonals. One possibility is that the production of wood products is more easily adapted to seasonals in demand than the production of animal products. The details of supply and demand conditions for different commodities and their implications for the behavior of the basis is interesting material for future research.

III. The Basis: Forecast Power and Premiums

The theory-of-storage view of futures prices in equation (2) is not controversial. There is another view that is the subject of long and continuing controversy. The difference between the futures price and the current spot price can be expressed as the sum of an expected premium and an expected change in the spot price:

$$F(t, T) - S(t) = E_t[P(t, T)] + E_t[S(T) - S(t)], \tag{4}$$

where the expected premium is defined as the bias of the futures price as a forecast of the future spot price,

$$E_t[P(t, T)] = F(t, T) - E_t[S(T)]. \tag{5}$$

Equation (4) and the theory of storage in (2) are alternative but not competing views of the basis. Variation in the expected premium or the expected change in the spot price in (4) translates into variation in the interest rate, the marginal storage cost, or the marginal convenience yield in (2). For example, the basis for agricultural commodities is often negative before a harvest when the futures price is for delivery

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after the harvest. Under the theory of storage, the basis is negative because inventories are low and the convenience yield is larger than interest and storage costs. In terms of (4), the explanation for negative values of the basis is that the spot price is expected to fall when a harvest will substantially increase inventories. Likewise, positive values of the basis when both the futures and the spot prices are for the period between harvests can be explained in terms of storage costs that outweigh marginal convenience yields when inventories are high, but they are equally well explained in terms of an expected increase in the spot price necessary to induce storage between harvests.

Despite research that extends from Keynes (1930), Hardy (1940), Working (1948, 1949), Telser (1958, 1967), and Cootner (1960, 1967) to Dusak (1973), Bodie and Rosansky (1980), Carter, Rausser, and Schmitz (1983), and Hazuka (1984), there is little agreement on whether the expected premium in (4) is nonzero or on whether futures prices have power to forecast future spot prices. We test for time-varying expected premiums and price forecasts in futures prices with the regression approach in Fama (1984*a*, 1984*b*). Consider the regressions of the change in the spot price and the premium on the basis:

$$S(T) - S(t) = a_1 + b_1[F(t, T) - S(t)] + u(t, T), \tag{6}$$

$$F(t, T) - S(T) = a_2 + b_2[F(t, T) - S(t)] + z(t, T). \tag{7}$$

Evidence that b_1 is positive means the basis observed at t contains information about the change in the spot price from t to T. Equivalently, the futures price has power to forecast the future spot price. Evidence that b_2 is positive means the basis observed at t contains information about the premium to be realized at T. Predictable variation in realized premiums is evidence of time-varying expected premiums.

A. *What Can We Expect?*

Regressions (6) and (7) are subject to an adding-up constraint. The sum of the premium, $F(t, T) - S(T)$, and the change in the spot price, $S(T) - S(t)$, is the basis, $F(t, T) - S(t)$. Thus the intercepts in (6) and (7) must sum to 0.0; each period's residuals must sum to 0.0; and, most important, the slope coefficients must sum to 1.0. In other words, the regressions always allocate all variation in the basis to the expected premium, the expected change in the spot price, or some mix of the two.

The point is worth emphasizing. As law-abiding financial economists, we presume that market forecasts of future spot prices are rational. Moreover, all the spot and futures prices have been checked twice. Nevertheless, even basis variance due to measurement errors and irrational forecasts of spot prices are allocated by the regressions (6)

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TABLE 3 Standard Deviations of the 2-Month Basis, the Change in the Spot Price, and the Premium

Commodity	Basis $F(t, t+2) - S(t)$	Change $S(t+2) - S(t)$	Premium $F(t, t+2) - S(t+2)$
Agricultural products:			
Cocoa	4.0	14.6	15.2
Coffee	5.2	15.0	14.4
Corn	2.8	9.9	10.6
Cotton	2.4	9.0	9.0
Oats	4.4	11.7	10.5
Orange juice	4.9	13.1	13.4
Soybeans	2.8	12.2	12.0
Soy meal	4.1	13.4	13.4
Soy oil	4.7	13.5	13.7
Wheat	3.3	14.5	14.7
Wood products:			
Lumber	6.9	11.5	12.1
Plywood	3.2	9.8	10.5
Animal products:			
Broilers	5.8	11.1	8.7
Cattle	3.3	11.0	10.4
Eggs	13.2	16.3	12.6
Hogs	7.1	12.9	12.1
Pork bellies	1.9	16.9	16.4
Metals:			
Copper	2.5	12.1	12.4
Gold	.6	13.1	13.2
Platinum*	2.2	16.2	16.1
Silver	.5	18.5	18.7

* Two-month maturity is not available; 3-month maturity is used.

and (7). It is easy to show that an irrational forecast of the spot price in the futures price shows up as a time-varying expected premium (a positive value of b_2), while measurement error in the spot price shows up as forecast power (a positive value of b_1).

Although the regressions allocate all basis variation to expected premiums, expected spot-price changes, or some combination of the two, the allocation can be statistically unreliable. Since estimates of b_1 and b_2 in (6) and (7) are typically between 0.0 and 1.0, the regressions can fail to identify the source of variation in the basis—the regressions produce slope coefficients that sum to 1.0 but are not reliably different from 0.0—when basis variation is low relative to variation in realized premiums and changes in spot prices. We can get a good idea about where to place our bets in the regressions by examining variances of the basis relative to variances of premiums and changes in spot prices.

Table 3 shows standard deviations of the basis, $F(t, t + 2) - S(t)$, the change, $S(t + 2) - S(t)$, and the premium, $F(t, t + 2) - S(t + 2)$, for each commodity. The 2-month maturity is chosen because it is available for all commodities but platinum. In table 3 (and in the regressions below) all prices are measured in natural logs.

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The standard deviations of spot-price changes and premiums are large, and they do not differ much across commodity groups. For example, the standard deviations of spot-price changes range from 12.1% to 18.5% for the metals, from 9.0% to 15.0% for the agricultural products, and from 11.0% to 16.9% for the animal products. It seems that futures markets exist for commodities subject to similar high levels of uncertainty about future spot prices.

In contrast, basis variability differs systematically across commodity groups. As in table 2, the basis standard deviations in table 3 are smallest for the metals, larger for the agricultural and wood products, and largest for some of the animal products. The standard deviation of the 2-month basis for gold is 0.6% versus 7.1% for hogs. For commodities such as the metals, where basis variation is low relative to the variation of premiums and spot-price changes, it is unlikely that regressions (6) and (7) can reliably assign basis variation to expected premiums or expected spot-price changes. The regressions have a better chance with commodities like the animal products, where basis variation is substantial.

B. Regression Results

Estimates of the change regression (6) and the premium regression (7) are given in table 4. Because they are the focal point of the evidence on forecast power and time-varying expected premiums, the slopes b_1 and b_2 for both (6) and (7) are reported, even though they must sum to 1.0. To limit the size of the table, only results for 2, 6, and 10 months to maturity are shown. These maturities tend to have the largest samples, and they are spaced fairly evenly among the possible maturities from 1 to 12 months.

We first categorize the regressions for different commodities according to whether futures prices show time-varying expected premiums, power to forecast spot prices, both, or neither. Then we relate the results to differences in conditions of production and storage.

Type SF—strong forecast power. Futures prices for broilers, eggs, hogs, and oats have reliable forecast power at every maturity (including those not shown in table 4), and they show no reliable evidence of time-varying expected premiums. The slopes in the change regressions for these commodities are all more than 2.6 standard errors from 0.0, and most are more than 4.0 standard errors from 0.0. Moreover, the forecast power of futures prices is nontrivial. For example, the coefficients of determination (R_1^2) in the change regressions for broilers are 0.40 and 0.42; for oats they range from 0.20 to 0.35.

Type GF—good forecast power but not for all maturities. The change regressions for cattle, pork bellies, soybeans, and soy meal indicate reliable forecast power in futures prices for at least one matu-

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TABLE 4 Regressions of the Spot Price Change and the Premium on the Basis:
$S(T) - S(t) = a_1 + b_1[F(t, T) - S(t)] + u(t, T)$,
$F(t, t) - S(T) = a_2 + b_2[F(t, T) - S(t)] - u(t, T)$

		2 Months							6 Months							10 Months						
Commodity	Max.	Obs.	b_1	b_2	$t(b_1)$	$t(b_2)$	R_1^2	R_2^2	Obs.	b_1	b_2	$t(b_1)$	$t(b_2)$	R_1^2	R_2^2	Obs.	b_1	b_2	$t(b_1)$	$t(b_2)$	R_1^2	R_2^2
Agricultural products:																						
Cocoa	221	56	−.03	1.03	−.07	2.09	.00	.07	36	−.08	1.08	−.16	2.26	.00	.13	54	.24	.76	.42	1.32	.01	.08
Coffee	137	38	.86	.14	1.91	.30	.09	.00	...	...	...	...	...	...	...	37	.46	.54	.65	.75	.03	.04
Corn	221	56	−.40	1.40	−.84	2.93	.01	.13	36	−.59	1.59	−.81	2.20	.02	.12	54	.48	.52	.91	.98	.03	.03
Cotton	207	53	.55	.45	1.06	.87	.02	.01	...	...	...	...	...	...	...	50	1.10	−.10	2.27	−.21	.16	.00
Oats	217	54	1.18	−.18	3.63	−.55	.20	.01	34	1.05	−.05	4.19	−.19	.35	.00	42	1.02	−.02	3.28	−.07	.29	.00
Orange juice	207	101	.28	.72	1.07	2.69	.01	.07	100	.57	.43	1.79	1.36	.06	.04	97	1.00	−.00	2.85	−.00	.20	.00
Soybeans	221	110	.80	.20	1.95	.49	.03	.00	108	.71	.29	2.36	.95	.09	.02	106	.63	.37	1.71	1.01	.07	.03
Soy meal	217	108	.44	.56	1.26	1.59	.02	.03	68	.50	.50	1.14	1.15	.03	.03	93	.65	.35	2.85	1.56	.14	.05
Soy oil	217	112	.40	.60	1.41	2.11	.02	.04	75	−.02	1.02	−.07	2.75	.00	.16	105	.01	.99	.03	2.11	.00	.14
Wheat	219	55	.18	.82	.29	1.36	.00	.03	35	−.65	1.65	−1.33	3.39	.05	.25	52	−.78	1.78	−1.62	3.69	.07	.27
Wood products:																						
Plywood	163	81	−.00	1.00	−.02	3.42	.00	.13	79	.53	.47	1.46	1.29	.06	.05	69	1.27	−.27	3.81	−.80	.34	.02
Lumber	173	86	.35	.65	1.97	3.71	.04	.14	84	.28	.72	1.35	3.55	.05	.27	52	.16	.84	.42	2.21	.01	.24
Animal products:																						
Broilers	152	108	1.22	−.22	7.68	−1.40	.40	.02	64	.93	.07	5.39	.40	.42	.00	...	...	...	...	...	...	...
Cattle	147	51	1.12	−.12	2.51	−.27	.11	.00	67	.84	.16	1.54	.30	.07	.00	...	...	...	...	...	...	...
Eggs	173	145	.80	.20	8.58	2.15	.42	.04	80	.97	.03	6.24	.18	.53	.00	...	...	...	...	...	...	...
Hogs	217	117	.72	.28	4.59	1.81	.16	.03	103	.66	.34	2.67	1.38	.12	.04	78	.80	.20	2.76	.70	.22	.02
Pork bellies	219	37	2.77	−1.77	1.95	−1.25	.10	.04	33	1.39	−.39	5.12	−1.43	.45	.06	36	1.12	−.12	5.08	−.53	.53	.01
Metals:																						
Copper	223	157	−.03	1.03	−.08	2.57	.00	.05	92	.64	.36	1.54	.88	.05	.02	98	.66	.34	1.36	.70	.06	.02
Gold	115	107	−2.20	3.20	−.80	1.17	.01	.02	55	−1.74	2.87	−.68	1.04	.02	.05	52	−2.83	3.83	−.89	1.20	.07	.12
Platinum	199	...	...	...	...	...	...	...	65	.73	.27	.82	.30	.02	.00	...	...	...	...	...	...	...
Silver	211	174	−8.56	9.56	−2.45	2.73	.06	.07	100	−7.82	8.82	−2.50	2.82	.13	.16	99	−6.12	7.12	−2.03	2.36	.14	.17

NOTE.—R_1^2 and R_2^2 are the coefficients of determination for the change and premium regressions, respectively. Since the change and premium regressions have the same explanatory variable and the two residuals sum to .0, their slope coefficients have the same standard error. The t-statistics, $t(b_1)$ and $t(b_2)$, are based on standard errors adjusted for the autocorrelation of the regression residuals induced by the overlap of the observations on $S(T) - S(t)$ and $F(t, T) - S(T)$. (See Hansen and Hodrick 1980.) Obs. is the number of observations in a regression, and Max. is the number of months in the sample period.

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rity and suggestive evidence of forecast power for other maturities. They show no reliable evidence of time-varying expected premiums.

Types SP and GP—expected premiums. The premium regressions for two commodities, soy oil and lumber, produce reliable evidence of time-varying expected premiums at every maturity, while three commodities—cocoa, corn and wheat—seem to have time-varying expected premiums at some but not all maturities. The evidence of time-varying expected premiums for these commodities is weaker than the evidence of forecast power for the SF and GF commodities. For example, t-statistics above 5.0 are common in the change regressions for the SF commodities, but the largest t-statistic in the premium regressions for the SP commodities is 3.71. Similarly, the coefficients of determination are often above 0.40 in the change regressions for the SF commodities, but they never exceed 0.27 in the premium regressions for the SP commodities.

Type F&P—forecast power and expected premiums. There are two commodities, orange juice and plywood, for which futures prices seem to show both forecast power and time-varying expected premiums. However, the evidence for forecast power occurs at long maturities, whereas the evidence for expected premiums is observed for shorter maturities.

Type W—weak. The regressions for coffee, copper, and cotton produce suggestive evidence that futures prices contain both time-varying expected premiums and power to forecast future spot prices; that is, for many maturities (including those not shown) the slope coefficients b_1 and b_2 for the change and premium regressions are both well above 0.0 and below 1.0. Some of the regression slopes for these commodities are more than 2 standard errors from zero, but most are not reliably different from 0.0. In short, the regressions fail to identify any commodities for which the basis shows reliable simultaneous variation in expected premiums and forecasts of spot prices.

For gold and platinum, basis variability is so low relative to the variability of realized premiums and changes in spot prices that regression coefficients equal to 1.0 would usually be less than 1 standard error from zero. For these commodities, the regressions cannot reliably identify situations in which all basis variation reflects either time-varying expected premiums or forecasts of spot-price changes. This is in contrast to the theory of storage regressions in table 2, where the basis is the dependent variable and the low basis variances of the precious metals allow the most reliable inferences that the basis tracks nominal interest rates.

The silver regressions in table 4 are puzzling. The regression slopes are more than 2.0 standard errors from zero, but the coefficients seem bizarre. For example, the estimated slope in the 2-month change regression is -8.56; taken literally, a 1.0% increase in the basis implies

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TABLE 5 Regression Scoreboard

Futures Prices Show:			
Forecast Power	Expected Premiums	Both	Neither (Weak)
Broilers* (SF) 4	Lumber (SP) 3	Orange juice* (F&P) 6	Coffee (W) 5
Eggs* (SF) 1	Soy oil (SP) 7	Plywood (F&P) 13	Copper (W) 16
Hogs* (SF) 2			Cotton (W) 17
Oats* (SF) 8	Cocoa (GP) 10		Gold (W) 21
	Corn* (GP) 15		Platinum (W) 18
Cattle* (GF) 11	Wheat* (GP) 12		Silver (W) 20
Pork bellies* (GF) 19			
Soybeans* (GF) 14			
Soy meal (GF) 9			

NOTE.—An asterisk means the commodity's basis shows reliable evidence of seasonals in the estimates of (3). The numbers after the commodities are the (reverse) order of their basis standard deviations for the 2-month maturity in table 3. For example, the 1 after eggs indicates that its basis has the highest standard deviation. The letters in parentheses after the commodity names categorize their regression results in the estimates of (5) and (6) in table 4. The categories are as follows. SF = strong forecast power: statistically reliable power to forecast changes in spot prices across all maturities; no evidence of time-varying expected premiums. GF = good forecast power: statistically reliable power to forecast changes in spot prices for most but not all maturities; no evidence of time-varying expected premiums. SP = strong expected premiums: statistically reliable evidence of time-varying expected premiums across all maturities. GP = expected premiums: statistically reliable evidence of time-varying expected premiums for most but not all maturities. F&P = forecast power and expected premiums: statistically reliable forecast power for some maturities and statistically reliable time-varying expected premiums for others. W = weak: regression evidence is unreliable or extreme.

an 8.6% drop in the expected price change. We are examining these and other metal results in more detail.

C. *Interpretation of the Regressions*

Table 5 summarizes the regressions, both those in table 4 and the theory of storage regressions in table 2. Commodities are allocated to the columns of table 5 depending on whether their futures prices show forecast power or time-varying expected premiums in (6) and (7). The numbers after the commodity names are the reverse order of their basis standard deviations for the 2-month maturity in table 3. An asterisk means that the commodity's basis shows seasonals in table 2.

1. *Basis variability, forecast power, and premiums.* As expected, there is a relation between basis variability and evidence that futures prices have time-varying expected premiums or power to forecast future spot prices. Of the four commodities that show strong forecast power (SF) in the estimates of (6), three—broilers, eggs, and hogs—rank in the top four in basis variability. Two commodities, lumber and soy oil, show evidence of time-varying expected premiums (SP) for all maturities; lumber ranks third in basis variability, and soy oil is seventh. At the other end of the spectrum, copper, cotton, gold, and platinum have relatively low basis variation and unreliable results in the tests for forecast power and premiums.

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Since the slopes in the regressions of $S(T) - S(t)$ and $F(t, T) - S(T)$ on $F(t, T) - S(t)$ sum to 1.0 and are typically between 0.0 and 1.0, it is almost a matter of arithmetic that regression coefficients statistically far from 0.0 in (6) and (7) occur when basis variation is high relative to the variation of the changes and premiums to be explained. The interesting question is why basis variation is high for some commodities and low for others.

2. *Storage costs and forecast power.* As discussed earlier, the theory of storage predicts that storage costs are important in explaining differences in the variability of the expected spot-price change in the basis. For agricultural and animal products, which are subject to seasonals in production or demand, the amount of predictable seasonal variation in the spot price should be an increasing function of storage costs. Likewise, stored stocks act to smooth predictable adjustments in the spot price in response to demand and supply shocks. Since storage costs that are high relative to value deter storage, the theory predicts that variation in expected spot-price changes in response to shocks is also an increasing function of storage costs.

These predictions can explain broad features of the estimates of the change regression (6). The regressions for eight commodities indicate that the basis $F(t, T) - S(t)$ has reliable information about the future change in the spot price $S(T) - S(t)$ for most maturities $(T - t)$. Five of these commodities are animal products (broilers, cattle, eggs, hogs, and pork bellies), whose bulk and perishability imply high storage costs relative to value. Storage costs (table 2) are also high for the remaining three commodities (oats, soybeans, and soy meal), whose futures prices show consistent forecast power. Forecast power is not found in futures prices for gold and platinum, whose storage costs are low relative to value and basis variances are low relative to variances of spot-price changes.[1]

3. *Seasonals and forecast power.* Our analysis of storage costs and forecast power predicts that seasonal variation in the basis generates forecast power in the change regression (6). Table 5 suggests that this prediction is generally correct. The basis has reliable power to forecast changes in the spot price for eight of the 10 commodities that have reliable basis seasonals. Of the 10 commodities with reliable evidence of forecast power, eight have reliable basis seasonals.

D. Univariate Tests for Expected Premiums

The estimates of (7) find evidence of expected premiums for only seven of 21 commodities. The regressions, however, are designed to detect

1. Hazuka (1984) estimates (6) for 1-month spot-price changes and for a shorter list of commodities. His conclusions about the relation between storage costs and forecast power are similar to ours. He does not recognize that the change regression (6) has a complement, the premium regression (7).

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variation in expected premiums. Failure to identify time-varying expected premiums does not imply that expected premiums are zero. To examine the issue further, we have computed average values of the premium, $F(t, T) - S(T)$, for each maturity of each commodity. This approach has no power (i) because the variances of realized premiums are so large (see table 3) and (ii) because futures contracts for a given maturity $(T - t)$ are available for only a fraction of the sample months (compare the maximum and actual observations in table 4).

Following Bodie and Rosansky (1980), we increase the power of univariate tests for expected premiums by (i) combining contracts for a commodity to ensure that an observation for the commodity is available every month and (ii) combining commodities into portfolios. Monthly returns are computed for each commodity using the shortest futures contract with at least 1 month to maturity on the first trading day of each month. A simple return is defined as the change in the futures price over the month, divided by the price of the contract at the beginning of the month. Contracts chosen generally have maturities of 1, 2, or 3 months.

The average simple returns for individual commodities (table 6) suggest that futures prices show normal backwardation—the expected return from a long futures position is positive. The average simple returns for 19 of the 21 commodities are positive, and the average returns for cocoa, coffee, orange juice, soy oil, and hogs are larger than 1.0% per month. However, the evidence for normal backwardation is weaker than these averages suggest. Standard deviations of monthly returns for individual commodities are often greater than 10.0%. As a consequence, the average simple returns for only five commodities produce t-statistics greater than 2.0. With continuous compounding, only the average return for eggs is more than 2.0 standard errors from 0.0—and that return is negative.

If normal backwardation is the normal case, combining commodities into portfolios does not smear information about expected premiums, and the power of tests for expected premiums is improved. We average the simple monthly returns on individual commodities to get equally weighted portfolio returns. A portfolio of all 21 commodities and portfolios that include natural subgroups are examined.

The average simple return on the portfolio of all commodities is 0.54% per month. Its t-statistic is 1.87. Thus on the average the monthly changes in futures prices for commodities show marginally reliable normal backwardation that is also nontrivial in magnitude. This conclusion is tempered by the continuously compounded returns. With continuous compounding the average portfolio return falls from 0.54% to 0.45% per month, and its t-statistic falls to 1.57. The nontrivial differences between average simple and continuously compounded returns are easily explained. Even the return on the portfolio of all com-

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TABLE 6 **Average Monthly Simple and Continuously Compounded Returns for Portfolios and Individual Commodities**

		Simple			Continuously Compounded		
	Obs.	*M*	SD	*t*(*M*)	*M*	SD	*t*(*M*)
All commodities	222	.54	4.3	1.87	.45	4.2	1.57
Agricultural products:	222	.83	5.4	2.29	.69	5.2	1.97
Cocoa	220	1.59	10.1	2.33	1.10	9.8	1.67
Coffee	140	1.84	10.2	2.13	1.35	9.6	1.67
Corn	220	.12	6.6	.27	−.09	6.5	−.21
Cotton	208	.32	7.1	.66	.09	6.8	.18
Oats	218	.10	7.6	.19	−.19	7.6	−.36
Orange juice	209	1.37	11.2	1.76	.83	10.0	1.20
Soybeans	220	.66	9.7	1.01	.21	9.4	.34
Soy meal	213	.86	10.9	1.15	.31	10.3	.44
Soy oil	218	1.91	11.4	2.47	1.31	10.6	1.83
Wheat	218	.06	9.1	.10	−.30	8.4	−.54
Wood products:	177	−.23	7.5	−.42	−.51	7.5	−.91
Lumber	177	−.53	7.9	−.89	−.86	8.1	−1.40
Plywood	165	.44	8.0	.71	.13	7.8	.22
Animal products:	220	.00	6.3	.00	−.20	6.3	−.46
Broilers	151	.55	7.4	.92	.31	6.9	.56
Cattle	151	.24	7.0	.42	−.01	7.1	−.01
Eggs	175	−2.01	10.4	−2.56	−2.60	10.7	−3.20
Hogs	220	1.11	8.0	2.06	.79	8.0	1.47
Pork bellies	218	.26	10.4	.37	−.28	10.5	−.39
Metals:	222	.57	8.3	1.02	.23	8.1	.43
Copper	222	.35	8.2	.63	.01	8.2	.02
Gold	114	.32	9.0	.38	−.06	8.7	−.08
Platinum	119	.17	9.4	.26	−.26	9.4	−.40
Silver	209	.95	12.3	1.11	.25	11.8	.31

NOTE.—*M* is the average return. SD is the standard deviation of the return. *t*(*M*) is the *t*-statistic for the average return.

modities has substantial variability. The standard deviations of its simple and continuously compounded returns are 4.3% and 4.2% per month.[2] Among subgroup portfolios, the highly diversified portfolio of agricultural products produces *t*-statistics around 2.0 in the simple and continuously compounded returns, but the *t*-statistics for the average returns for the remaining portfolios are 1.02 or less.

In short, large average premiums sometimes produce marginal evidence of nonzero expected premiums when the futures contracts for commodities are combined into portfolios. Even for portfolios, inference is sensitive to whether we use simple or continuously com-

2. Fama and Schwert (1979) report that the standard deviation of monthly rates of change in the U.S. Consumer Price Index (CPI) is about 0.25%. The standard deviations of the monthly rates of change of the nine major components of the CPI never exceed 0.62%. These numbers are trivial relative to the standard deviations in table 6. It seems safe to conclude that general inflation is a negligible component of the short-term variation in futures prices.

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pounded returns, and the evidence is never strong. These results provide a good perspective on the problems of inference posed by the variability of futures prices—and on the persistence of the debate about the existence of expected premiums.

IV. Summary

Two views of commodity futures prices are common. The theory of storage summarized in equation (2) explains the difference between a futures price and the contemporaneous spot price (the basis) in terms of interest forgone in storing a commodity, warehousing costs, and a convenience yield from inventory. The alternative view of equation (4) splits a futures price into an expected premium and a forecast of the maturity spot price.

Although the two models are alternative perspectives on the same economic phenomena, developing evidence on them presents different statistical problems. Evidence on forecast power and expected premiums in futures prices is extracted from realized spot-price changes and premiums, in the manner, for example, of regressions (6) and (7). A typical characteristic of commodities traded in futures markets is highly uncertain future spot prices. For many traded commodities, basis variances that are large in absolute terms are small relative to the variances of realized premiums and spot-price changes. As a consequence, although regressions (6) and (7) allocate all basis variation to expected premiums and expected changes in spot prices, for many commodities the allocation is not statistically reliable, and nonzero variances of the two expected values in the basis cannot be separately identified.

Likewise, the large variances of realized premiums mean that average premiums that often seem economically large are usually insufficient to infer that expected premiums are nonzero, especially in the data for individual commodities. When commodities are combined into portfolios, statistical power is increased and marginal evidence of normal backwardation is obtained. But the evidence is not strong enough to resolve the long-standing controversy about the existence of nonzero expected premiums.

In contrast, regressions in which the basis is the dependent variable are used to test whether the basis varies with interest rates, warehousing costs, and convenience yields in the manner predicted by the storage-cost model of (2). Since variation in the basis is not buried in extraneous noise—even with a crude approach like the regression (3) of the basis on the nominal interest rate and seasonal dummies—the tracks of the storage-cost variables in the basis are identified more easily than variation in the basis due to expected premiums and forecasts of future spot prices.

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The results for the precious metals and the animal products illustrate the different statistical problems. The low basis variances of the precious metals allow precise estimation of the interest-rate response predicted in (2), but they preclude a reliable split of the basis between the expected premium and the expected spot-price change in (4). At the other extreme, the high basis variances of the animal products preclude reliable estimates of the interest-rate coefficient in (2), but they allow us to infer that futures prices have power to forecast future spot prices.

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