Business cycles and the behavior of energy prices

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This paper tests the theory of storage--the hypothesis that the marginal convenience yield on inventory falls at a decreasing rate as inventory increases in energy markets (crude oil, heating oil, and unleaded gas markets). We use the Fama and French (1988) indirect test, based on the relative variation in spot and futures prices. The results suggest that the theory holds for the energy markets.

INTRODUCTION

The theory of storage, which postulates that the marginal convenience yield on inventory falls at a decreasing rate as aggregate inventory increases, is the dominant model of commodity futures prices [see, for example, Brennan (1958), Telser (1958), and Working (1949)]. This hypothesis can be tested either directly by relating the convenience yield to inventory levels utilizing a simple statistical model [as in Brennan (1958) and Telser (1958)], or indirectly by testing its implication about the relative variation of spot and futures prices [as in Fama and French (1988)].

In this paper we test the theory of storage in energy markets--crude oil, heating oil, and unleaded gas. Although the theory of storage was advanced mainly for commodities subject to seasonal variation in supply (i.e., harvest), an examination of the theory is also warranted for energy products. While energy products do not exhibit seasonal supply variations due to a harvest, they are subject to other supply and demand seasonal fluctuations. For example, although the supply of crude oil and other refined products is not inherently seasonal, heating oil has demand peaks during the winter and gasoline has demand peaks during the summer.

Early attempts at testing the theory of storage and the convenience yield hypothesis used industry inventory data and market prices. However, because of the difficulty in defining and measuring the relevant inventory, rather than test the theory by examining the inventory-convenience yield relation directly, we follow Fama and French (1988) and test the theory's implications about the relative variation of spot and futures prices. These implications can be viewed as refinements of Samuelson's (1965) hypothesis that [under the assumption that spot prices follow a stationary (mean-reverting) process, and futures prices are unbiased estimates for the settlement cash prices] futures prices vary less than spot prices and that the variation of futures prices is a decreasing function of maturity--see also Serletis (1992).

The remainder of the paper consists of four sections. The first section briefly discusses the theory of storage. The second section describes the data and the third section presents the empirical results. The final section summarizes the paper.

THEORETICAL FOUNDATIONS

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 and let R(t, T) denote the interest rate at which market participants can borrow or lend over a period starting at date t and ending at date T. The theory of storage says [see Fama and French (1988)] that the basis--the current futures spot differential, F(t, T) - S(t) --equals the interest foregone during storage, s(t) R(t, T), plus the marginal warehousing cost, W(t, T), minus the marginal convenience yield, C(t, 7). That is

$$F(t,T) - S(t) = s(t) R(t,T) + W(t,T) - C(t,T) \quad (1)$$

The storage equation (1) is also known as the cost-of-carry pricing relationship and equates basis with the cost of carry, so that arbitrage is not profitable. Clearly, positive carrying costs result in a positive basis--that is, a futures price above the spot market price. In such cases the buyer of a futures contract pays a premium for deferred delivery, known as contango. Negative carrying costs imply a negative basis--that is, a futures price below the spot market price. This type of price relationship is known as backwardation.

Dividing both sides of the storage equation (1) by s(t) and rearranging, we obtain

$$\frac{F(t,T) - S(t)}{S(t)} - R(t,T) = \frac{W(t,T) - C(t,T)}{S(t)} \quad (2)$$

According to equation (2), the observed quantity on the left-hand side--the interest adjusted basis, [F(t, 7) - s(t)]/s(t) - R(t, T) --is the difference between the relative warehousing cost, W(t,T)/S(t), and the relative convenience yield, C(t,T)/S(t).

Assuming that the marginal warehousing cost is roughly constant, that the marginal convenience yield declines at a decreasing rate with increases in inventory [see, for example, Brennan (1958) and Telser (1958)], and that variation in the marginal convenience yield dominates variation in the marginal warehousing cost, we can use the interest-adjusted-basis equation (2) to develop testable hypotheses about the convenience yield. For example, when inventory is low, the relative convenience yield is high and larger than the relative warehousing cost, and the interest-adjusted basis becomes negative. On the other hand, when inventory is high, the relative convenience yield falls toward zero, and the interest-adjusted basis becomes positive and increases toward the relative warehousing cost.

Moreover, the theory of storage and the concept of declining marginal convenience yield on inventory allow us to make predictions about the impact of demand and supply shocks on the relative variation of spot and futures prices. For example, when inventory is high (the convenience yield is low and the interest-adjusted basis is positive) a permanent demand shock causes a large inventory response but a small change in the convenience yield or the interest-adjusted basis. In this case spot and futures prices have roughly the same variability, suggesting that changes in spot prices are largely permanent--they show up one-for-one in futures prices. However, when inventory is low (the convenience yield is high and the interest-adjusted basis is negative) demand shocks produce small changes in inventories but large changes in the convenience yield and the interest-adjusted basis. In this case, shocks cause spot prices to change more than futures prices and the basis is more variable than when inventories are high.

In what follows, we test the theory of storage in energy markets. Because of the difficulty, however, in defining and measuring the relevant inventory, rather than using direct tests by relating the convenience yield to inventory levels [see, for example, Brennan (1958) and Telser (1958)], we use the Fama and French (1988) indirect tests based on the relative variation in spot and futures prices. In particular, using the sign of the interest adjusted basis as a proxy for high (+) and low (-) inventory, the prediction of the theory of storage that shocks produce more independent variation in spot and futures prices when inventory is low implies that the interest-adjusted basis is more variable when it is negative--see French (1986) for a derivation and detailed discussion.

DATA

To test the theory of storage we use daily observations from the New York Mercantile Exchange (NYMEX) on one-month, two-month, four-month, and seven-month futures prices for crude oil, heating oil and unleaded gasoline. In fact, we use the spot-month futures prices as a proxy for current cash prices, the second-month futures prices as a proxy for the current futures prices, and similarly the fourth-month and seventh-month futures prices as proxies for the three-month and six-month futures prices, respectively.

The sample period is June 1, 1983 to April 27, 1992 for crude oil, August 7, 1983 to April 27, 1992 for heating oil, and December 3, 1984 to April 27, 1992 for unleaded gas. Because of daily price limits, as well as technical trading adjustments [such as, for example, abrupt movements in the price of the spot-month futures contracts on their last trading day, as traders adjust themselves out of positions], daily prices have been converted to weekly average price series. Such averaging tends to smooth these erratic price movements.

TEST RESULTS

To investigate the theory of storage prediction that the interest-adjusted basis is more variable when it is negative (because shocks produce more independent variation in spot and futures prices when inventory is low), Tables 1-3 report the standard deviations of weekly as well as daily changes in the interest-adjusted basis for one, three and six month crude oil, heating oil and unleaded gas futures contracts. Clearly, the standard deviation for crude oil is only slightly more variable when it is positive than when it is negative, but the standard deviations for heating oil and to a lesser extent for unleaded gas are larger when the interest-adjusted basis is negative. Moreover, F-tests reject (in general) the null hypothesis of equal variances. Hence, we conclude that the heating oil and unleaded gas markets pass this Fama-French (indirect) test.

As it was argued earlier, the theory of storage also implies that shocks produce roughly equal changes in spot and futures prices when inventory is high and the interest-adjusted basis is positive, but more variation in spot prices than in futures prices when inventory is low and the interest-adjusted basis is negative. To investigate this prediction of the theory of storage, we report in Table 4 the ratios of the standard deviation of percent futures price changes to the standard deviation of percent spot price changes for the weekly as well as the daily data. Clearly, the ratios are lower when the interest-adjusted basis is negative for all three commodities, thereby confirming the theory of storage prediction about the response of spot and futures prices to demand and supply shocks.

The theory of storage also predicts that shocks produce larger changes on shorter maturity futures prices than on longer maturity futures prices because the shocks are progressively offset by demand and supply responses. Thus, the ratios of the standard deviation of futures price changes to the standard deviation of spot price changes in Table 4 should decrease with increasing maturities. Clearly, the ratios are consistent with this prediction. For example, in the case of crude oil, the ratios for weekly positive interest-adjusted bases fall from 0.90 at one month to 0.85 at three months and 0.75 at six months. The ratios for negative interest-adjusted bases are 0.88, 0.78, and 0.71. This evidence is consistent with Samuelson's (1965) hypothesis about the relative variation of spot and futures prices.

CONCLUSION

This paper uses the sign of the interest-adjusted basis as a proxy for high (+) and low (-) inventory. We test the prediction of the theory of storage that, when inventory is high, large inventory responses to shocks imply roughly equal changes in spot and futures prices. When inventory is low, smaller inventory responses to shocks imply larger changes in spot prices than in futures prices. Tests on spot and futures crude oil, heating oil, and unleaded gas prices confirm these predictions.

Our empirical validation of the theory of storage supports the theory's wide acceptance by market participants. In fact, as Cho and McDougall (1990,p. 611) put it "...the theory of storage is widely accepted by participants of energy futures markets. Market participants, for example, interpret a large negative time basis (i.e., the futures price is significantly lower than the spot price) as a signal to draw energy products out of storage and a small negative basis or positive basis as a signal to store commodities. Refiners frequently rely on basis in timing their crude oil purchases and in scheduling production and delivery of refined products."

Confirmation of the theory of storage is also important in modelling futures prices. Since the theory suggests that futures prices are largely determined by demand and supply conditions in spot markets, the issue is whether futures markets are backward or forward looking. In this regard, Serletis and Banack (1990) use recent developments in the theory of nonstationary regressors to test (in the context of energy markets) the hypothesis that futures prices are unbiased predictors of future spot prices. They find support for the hypothesis. Also, Serletis (1991) uses Fama's (1984) variance decomposition approach to measure the information in energy futures prices about future spot prices and time varying premiums. He finds that the premium and expected future spot price components of energy futures are negatively correlated and that most of the variation in futures prices is variation in expected premiums. Clearly, whether energy futures markets are backward or forward looking is an area for potentially productive future research.

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Table 1 Standard Deviations of Changes in the Crude Oil Interest-Adjusted Basis

	Daily Data			Weekly Data		
Contract	Positive	Negative	All	Positive	Negative	All
PART A: Standard Deviations of Changes in the Interest-Adjusted Basis						

1-Month	0.20	0.16'[[b]]	0.17	0.22	0.16[b]	0.17
3-Month	0.06	0.06	0.06	0.08	0.08	0.08
6-Month	0.04	0.03[b]	0.03	0.06	0.05[c]	0.05
PART B: Number of Observations						
l-Month	400	1630	2030	84	380	464
3-Month	281	1749	2030	56	407	464
6-Month	182	1848	2030	35	428	464

NOTES: Statistics are for observations when the interest-adjusted basis is positive (Positive), observations when the interest-adjusted basis is negative (Negative), and for all observations (All). Interest rates in the interest-adjusted basis are yields on U.S. Treasury bills, from the Bank of Canada. Significant (rejection of the null hypothesis of equal variances) at the [b]one percent, 'five percent, and c ten percent level.

Table 2 Standard Deviations of Changes in the Heating Oil Interest-Adjusted Basis

	Daily Data			Weekly Data		
Contract	Positive	Negative	All	Positive	Negative	All
PART A: Standard Deviations of Changes in the Interest-Adjusted Basis						
l-Month	O.14	0.21[b]	0.18	0.12	0.26[b]	0.22
3-Month	0.05	0.09[b]	0.08	0.06	0.14[b]	0.12
6-Month	0.04	0.04	0.04	0.04	0.07[b]	0.07
PART B: Number of Observations						
1-Month	888	1179	2067	189	271	460
3-Month	716	1351	2067	152	308	460
6-Month	521	1546	2067	116	344	460

NOTES: Statistics are for observations when the interest-adjusted basis is positive (Positive), observations when the interest-adjusted basis is negative (Negative), and for all observations (All). Interest rates in the interest-adjusted basis are yields on U.S. Treasury bills, from the Bank of Canada. Significant (rejection of the null hypothesis of equal variances) at the [b]one percent, [a]five percent, and[c]ten percent level.

Table 3 Standard Deviations of Changes in the Unleaded Gas Interest-Adjusted Basis

	Daily Data			Weekly Data		
Contract	Positive	Negative	All	Positive	Negative	All
PART A: Standard Deviations of Changes in the Interest-Adjusted Basis						
1-Month	0.21	0.20[c]	0.20	0.21	0.21	0.21
3-Month	0.07	0.08[b]	0.08	0.09	0. 11[b]	0.10

6-Month	0.03	0.04[b]	0.04	0.04	0.07[b]	0.06
		PART B: Number of Observations				
1-Month	523	1222	1745	105	267	372
3-Month	471	1274	1745	101	271	372
6-Month	311	1434	1745	65	307	372

NOTES: Statistics are for observations when the interest-adjusted basis is positive (Positive), observations when the interest-adjusted basis is negative (Negative), and for all observations (All). Interest rates in the interest-adjusted basis are yields on U.S. Treasury bills, from the Bank of Canada. Significant (rejection of the null hypothesis of equal variances) at the [b]one percent, [a]five percent, and[c]ten percent level.

Table 4 Ratios of the Standard Deviation of Percent Futures Price Changes

	Daily Data		Weekly Data	
Contract	Positive	Negative	Positive	Negative
		PART A: Crude Oil		
1-Month	0.85[c]	0.84[b]	0.90	0.88
3-Month	0.79[[a]]	0.71[b]	0.85	0.78[b]
6-Month	0.69[b]	0.69[b]	0.75	0.71 [b]
		PART B: Heating Oil		
1-Month	0.87[[a]]	0.80[b]	0.93	0.83[[a]]
3-Month	0.80[b]	0.70[b]	0.83	0.75[b]
6-Month	0.70[b]	0.64[b]	0.73[[a]]	0.66[b]
		PART C: Unleaded Gas		
1-Month	0.91	0.83[b]	0.93	0.90
3-Month	0.82[[a]]	0.75[b]	0.89	0.79[[a]]
6-Month	0.88	0.70[b]	0.88	0.73[[a]]

NOTES: Statistics are for observations when the interest-adjusted basis is positive (Positive) and for observations when the interested-adjusted basis is negative (Negative). Significant (rejection of the null hypothesis of equal variances) at the [b]one percent, [a]five percent, and[c]ten percent level.

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