Convenience Yields as Call Options: An Empirical Analysis

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INTRODUCTION

This article examines empirically the behavior and determinants of convenience yield over time for four storable commodities. Contrary to previous approaches, convenience yields are treated as call options with identifiable exercise price, time to maturity and underlying asset. The empirical results derived from the analysis of price and stock data covering the period 1966 to 1995, are in line with previous evidence that convenience yields are negatively related to inventory levels. Furthermore, it is demonstrated that observed convenience yields are valued as call options according to an extension of the Black–Scholes option pricing model.

The concept of convenience yield is not new. Early authors [Kaldor (1939); Working (1948, 1949)] have defined it as a negative component of carrying charges in an effort to explain the often observed phenomenon of spot prices being higher than futures prices. This definition presents convenience yield as a benefit which accrues to inventory holders from the increased utility associated with availability at periods of scarce supplies.

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Both the early empirical investigation [Brennan (1958); Telser (1958)] as well as more recent research on a large number of commodities [Brennan (1986); Fama and French (1987)] have provided strong support for the negative relationship between convenience yields and inventory levels. Furthermore, Fama and French have documented a time-varying behavior of convenience yield related to seasonality of crop-related commodities, which suggests that differences in the supply mechanism produce differential behavior in convenience yields.

The differential behavior of convenience yield under various regimes of demand and supply has been the subject of recent theoretical work in this area. Bresnahan and Spiller (1986) offered an important model of interaction between consumption and storage which accounts explicitly for the yield to stored commodities, due to demand shocks which drive spot price above futures price. Milonas and Thomadakis (1989) studied a two-period model in which demand is random and supply is given by production prior to the beginning of first period and at the end of second period. As a result, stored inventories play the role of absorbing demand fluctuations between production dates. Any demand/supply imbalance which leads to a stockout is bound to push spot prices higher than futures prices and thus result in a convenience yield. Using arbitrage arguments the authors showed that convenience yields have the payoff structure of a call option.

Heinkel, Howe, and Hughes (1990) also treated convenience yields as options. Utilizing profit maximization at the level of firms, they identified the determinants of commodity convenience yields. Their two-period model confirms the earlier finding of an inverse relationship between inventory levels and convenience yields. Furthermore, it links convenience yields directly with marginal production costs and hypothesizes an inverse relationship between convenience yields and sport price serial correlation.

Finally, in a model departing from previous approaches, Wright and Williams (1989) attempted to explain the observed phenomenon of positive storage when spot prices exceed futures prices not by the existence of convenience yield but rather by the existence of economically distinct subaggregates of the commodity. They also introduced the explanation that the variability of the marginal cost of transformation is embedded in each commodity because of its geographical location or ability to be transformed into other commodities. This approach gives convenience yields a broader definition which focuses not on the spot/futures price spread so much, but on the option-like features that the handling of commodities entails either in the consumption/storage decision or in the product transformation decision.

Based on the recent theoretical approaches which view convenience yield as an option, this study conducts an empirical investigation of whether convenience yields have the characteristics of an option and whether conventional option pricing models can be used to evaluate them.

THEORY AND HYPOTHESES

To best motivate the design of the empirical tests, the three-date framework adopted by Milonas and Thomadakis (1989), and Heinkel et al. (1990) is used.

Date $t = 0$ is a date of production decisions. Date $t = 1$ is the date of output realization. An intermediate date, ($t = z$), represents an intermediate trading date. In crops with a definite production cycle, dates (0, 1) represent the beginning and end of the crop cycle; date (z) represents a date during the cycle at which future production cannot be altered but preexisting inventories can be stored or consumed. For example, in the case of wheat with an August-to-July cycle, date (0) would be August, date (1) would represent the following July, and date (z) could be the intervening month of December or any other time between August and July.

Assuming that spot and futures markets operate at every trading date, the implication of the theoretical arguments of Milonas–Thomadakis and Heinkel et al. is that

$$F(0,1) = P(0) + C(0,1) - V(0,1) \tag{1}$$

where F is a futures price contracted at time 0 for delivery in period 1, P is a spot price in period 0, C is a carrying charge, and V is the convenience yield of carrying stocks over the interval [0,1]. The value of V is equivalent to a call option, according to this argument. The option can be simply understood as follows: Inventory held from period 0 to z can be either kept on until $t = 1$, or liquidated at z. The latter outcome will be preferable only when the spot price exceeds the futures price (net of carrying charges) at time z; i.e., if and only if,

$$P(z) - F(z,1) + C(z,1) > 0 \tag{2}$$

This contingency is feasible if a stockout can occur with positive probability at time (z). In that case, the spot price, $P(z)$, can rise as high as demand warrants for spot market clearing; the futures price, $F(z,1)$, however, is limited by predicted supplies at time 1, so it cannot follow the contemporaneous spot price. Then the quantity in (2) represents the payoff to holders of inventory. Naturally, if a stockout does not occur, this payoff remains at zero. (In effect (2) appears as an equality in that case). Therefore, V is the value at $t = 0$ of the contingent claim for payoff (2) at time z. This is equivalent to a call option maturing at time z, with exercise price equal to the supply-constrained futures price at $t = z$, and underlying price equal to the randomly varying spot price in the intermediate period z.

Two hypotheses follow immediately from this scenario. The first $\{H1\}$ is about the level of inventories. As inventories held at $t = 0$ increase, the probability of stockout is reduced and V will also decline, ceteris paribus. This is of course the Kaldor–Working–Brennan hypothesis. The second $\{H2\}$ is about variability. Option valuation implies that as the variability of the underlying asset price increases so does the value of a call option. The underlying asset in this case is inventory held at time z, and its price is the spot price in that period. Hence, V is expected to increase with spot price variability.

Two additional hypotheses also follow. If one takes into account the fact that there are not one but many intermediate trading periods and that there are several futures contracts maturing in those periods over a commodity's crop cycle, the earlier argument implies that there will be a type of term structure of convenience yields. At each successive intermediate date within the crop cycle, stocks generally decline. Hence, the probability of stockout increases. Thus, a third hypothesis $\{H3\}$ is that the convenience yields associated with stocks held at various time points in the crop cycle must increase as maturities approach the end of the cycle. To see this more clearly, go back to the example of wheat. At the start of the cycle in August, inventories are taken for the whole period to the following July. Futures maturing in December, March, May, and July are traded in August. The difference in futures prices among contracts of these maturities conveys convenience yields. Thus, the convenience yield of holding stocks from December to March is given by:

$$V(\text{December, March}) = f(\text{August, March}) - f(\text{August, December}),$$

where $f(x,y)$ denotes the present value of the futures price of a contract traded in month x for delivery in month y^*. Hypothesis $\{H3\}$ then requires (for wheat) that,

$$V(\text{December, March}) < V(\text{March, May}) < V(\text{May, July}).$$

A last hypothesis implied by the Milonas–Thomadakis, Heinkel, et al. argument can be based on observation of price behavior over the crop cycle. If low or no convenience yields appear at the start of the crop cycle, then spot prices in intermediate dates are predicted to be closely linked to futures prices of contracts maturing at the end of the cycle. Note from (1) that if V is zero, the occurrence of nonzero payoff, as in (2), is improbable. Then, $P(z)$ and $F(z,1)$ are expected to be closely linked, differing only by carrying costs. Hence, hypothesis $\{H4\}$ is that the correlation of intermediate period spot and futures prices will be high when convenience yields are low and vice versa.

The value of the option that is described above and will be empirically examined next, derives from the inability to adjust the level of inventories at an intermediate period to meet the demand. Such inability is due to the nature and behavior of the production process of commodities and cannot be bypassed. The possibility that inventories from the southern hemisphere can be imported during the cycle, the availability of commodities from elsewhere at low cost, and the reduction of tariffs in international trade should reduce convenience yields and, thus, the value of the option over time. Yet, since there cannot be timely replenishment of inventories without significant costs, convenience yields or the option to sell spot at a higher price than futures will always exist. However, depending on the production process of the commodity (agricultural, energy, or metal), this option will vary in value depending on the flexibility of supply adjustment or the existence of substitutes that are available at any given time.[1]

TEST DESIGN AND MEASUREMENT

Testing for the determinants of convenience yields according to the implications of the proposed conceptual scheme can be done both across commodities and time periods. Four commodities are chosen for observation. Three are agriculturals with long crop cycles (soybeans, corn, wheat); one is a metal without production cycles (copper). For each commodity the term structure of future prices is observed from the vantage point of a "beginning month". For each of the agricultural commodities the "beginning month" ($t = 0$) depicts the start of the crop cycle and is chosen as that delivery date which comes after the harvest is complete and before new plantings. Correspondingly, the "final month" ($t = 1$) is

[1]In an effort to include commodities with different degrees of flexibility, silver is included in the empirical analysis. Because silver is found to have no convenience yields, it is not included in the final analysis.

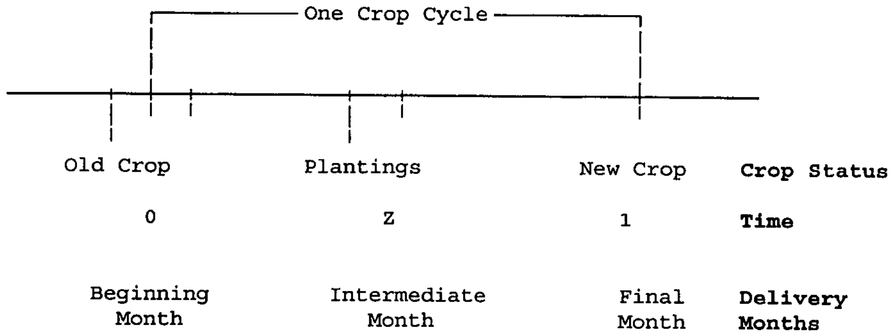

FIGURE 1
The timeframe in the model within one crop cycle.

TABLE I

Designation of Months for Each Commodity Within the Crop

	Crop Cycle Months		
Commodity	*Beginning*	*Intermediate*	*Final*
Soybeans	December	May	November
Corn	February	May	December
Wheat	August	December	July
Copper	December	May	December

designated as the delivery date closest to harvest completion. Finally, an intermediate delivery date ($t = z$) is picked as close as possible to the midpoint of the crop cycle. Since the agriculturals have a year-long cycle, year-long intervals of observation are used for copper, with a choice of three delivery dates as in the agriculturals, for purposes of comparison. Figure 1 illustrates the timeframe of the model within one crop cycle and Table I shows the selection of beginning, intermediate, and closing months for each commodity.

All observations of future price term structures within the yearly intervals defined by beginning and final months are taken from prices *in the beginning month.* Thus, the observation of convenience yields takes place at the start of the crop cycle of the agricultural commodities, after the actual size of the harvest is known. For example, the present value in December of convenience yield from holding stocks of soybeans from May to November is calculated from two futures prices observed in December:

$$V(\text{May, November}) = f(\text{December, May}) - f(\text{December, November}).$$

The level of inventories for agriculturals (I) is measured by observed quantities on and off farms at harvest time available at the beginning month, decreased by the *previous year's* first quarter percent reduction. Thus, the estimate of inventories being stocked beyond three months is based on information available at harvest time in each year. For copper, the previous year's total level of inventories is used.

An important step in this empirical approach is the use of an option valuation model for verification of the hypothesis that convenience yields behave as call options. The approach uses estimates of the exercise price and the volatility of the hypothesized option to compute an option value for convenience yield from a well-known valuation model (V^P). This predicted value is compared to actual values (V^A).

The option valuation model used is the one developed by Fisher (1978). In that model exercise price is assumed to be stochastic, and this assumption corresponds to the empirical environment of this study. Specifically, the call option which determines the value of convenience yield is an option whose exercise price is the futures price, $f(z,1)$, which will be experienced in period z, if all inventories are exhausted. From the viewpoint of period 0, this is a stochastic variable. The payoff of the option is the spot price observed in period z minus the exercise price. To estimate means and the requisite volatilities of these variables, observed spot and futures prices from all trading days in the month prior to the intermediate month are used.[2] The Fisher model requires estimation of the instantaneous proportional variance (s^2) of the change in the ratio of spot price to exercise price. This is estimated specifically as follows:

$$s^2 = \sigma_p^2 - 2r_{pf}\,\sigma_p\sigma_f + \sigma_f^2 \qquad (3)$$

where,

- σ_p^2 is the variance of daily logarithmic spot price relatives from all trading days in the month prior to the intermediate month.
- σ_f^2 is the variance of daily logarithmic price relatives of the futures contract maturing in the final month (used as exercise price here) from all trading days prior to the intermediate month.
- r_{pt} is the correlation coefficient between spot and futures prices estimated from the corresponding daily logarithmic price relatives in the month prior to the intermediate month.

[2]As stated, the payoff of the option is calculated in the intermediate month. Spot and futures prices from one month prior to the intermediate month are used to create an estimate of volatility that is close to that period. Yet, this estimate is independent from the pricing structure of the intermediate month which avoids introducing estimation errors.

The two main hypotheses of the article $\{H1$ and $H2\}$ are tested by regression analysis. This is performed as follows. To capture the option value component of convenience yields, the predicted value from the Fisher model is intended as an independent variable. Since, however, the stochastic features which have contributed to the estimation of V^P (spot and futures prices) may have dependence on the level of inventories, the effect of inventories on V^P is first expunged. Because this study examines the relationship over a long period of 30 years and it allows the level of inventories to be adjusted to new levels within the cycle (see footnote 1), option values are expected to have gradually decreased. To alleviate this, convenience yields are standardized by the level of spot prices. Furthermore, to reflect nonlinearities that exist between convenience yields and inventories, a logarithmic function has been utilized. Taking into account those concerns, the following regression is estimated first:

$$V^P/\text{spot} = a_0 + a_1 \log(I) + u \tag{4}$$

Subsequently, hypotheses $H1$ and $H2$ are tested by the regression:

$$V^A/\text{spot} = b_0 + b_1 \log(I) + b_2 u^* + e \tag{5}$$

where u^* is the residual estimated from regression (4). Hypothesis $H1$ predicts that $b_1 < 0$. $H2$ predicts that $b_2 > 0$, since the option value components are captured by the estimated residual u^*.

DATA

Daily spot and futures prices on soybeans, corn, wheat, and copper are from the Center for the Study of Futures Markets, Columbia University and the *Wall Street Journal* for the period, 1966 to 1989, and *The New York Times* for 1990 to 1995. For the same period, inventory data for agriculturals are from *Agricultural Statistics* and for copper from *Mineral Yearbook*. Finally, discount yield data on Treasury bills are from the *Wall Street Journal* and *The New York Times*.

For purposes of this study all futures prices are discounted to the time of observation using the Treasury bill discount yield which matures at the time of futures contract expiration using the following formula:

$$f(t,T) = F(t,T)\, e^{-i(t,T)\,(T-t)/365} \tag{6}$$

where $f(\cdot)$ is the discounted futures price, t is time of observation, T is the time of expiration, $i(t,T)$ is the T-bill discount yield over the interval

TABLE II

Predicted and Actual Mean Values of Convenience Yields

Commodity	*Mean Exp. Price*	*Mean σ^2*	*Mean V^A*	*Mean V^P*	*$V^P - V^A$ (t-Stat.)*	*Obs.*
Soybeans	281.12	0.19×10^{-3}	18.75	19.19	0.44 (0.14)	30
Corn	116.52	0.21×10^{-3}	5.21	5.84	0.63 (0.69)	30
Wheat	150.20	0.62×10^{-1}	10.03	8.59	−1.44 (−0.77)	29
Copper	34.64	0.38×10^{-3}	1.01	2.77	1.76 (2.02)[a]	29

Note: Wheat—1972 and Copper—1966 are excluded due to missing observations.
[a]Significant at the 5% level.
V^A—Actual mean value.
V^P—Predicted mean value.

(t,T), and $T - t$ the number of days until expiration. This discounting procedure is similar to what Brennan (1986) used. It attempts to adjust futures prices for the prevailing carrying charges. In this way all futures prices become free of carrying charges and can be easily compared with each other.[3] A final adjustment on spot and futures prices is made to reduce the impact of inflation. Because the study involves many years of data with varying levels of inflation, all prices are translated to price levels as of December 31, 1965. For the adjustment of agriculturals the Producer Price Index based on grains is used and, for copper, the Consumer Price Index.

EMPIRICAL ANALYSIS

Table II shows the estimations of convenience yields along with comparisons between means of actual and predicted values.

The results of Table II are encouraging. In the three commodities with crop cycle, the predicted mean convenience yields are very close to actual ones, despite the inaccuracies caused by imperfect approximations in the estimation of predicted values. Copper has a much larger divergence between predicted and actual convenience yields than the agriculturals despite the smaller size of convenience yields that copper exhibits.

[3]Equation (6) is used to transform observed futures prices $(F(t,T))$ into futures prices $(f(t,T))$ which are free from existing carrying costs between period t and T. In this way, the convenience yield or spread between futures and spot at a given time, $(f(t,T) - s(t))$, is left to capture other factors such as the flexibility to adjust inventories to new levels or the level of inventories at that time.

TABLE III

Cochrane–Orcutt Regression Results for V^P/spot $= a_0 + a_1 \log(I) + u$ (4)

Commodity	a_0	a_I	R^2	*No. Obs.*
Soybeans	0.296	−0.034	0.03	28
	(1.00)	(−0.77)		
Corn	0.143	−0.011	0.08	28
	(0.50)	(−0.33)		
Wheat	−0.513	0.076	0.13	26
	(−1.72)	(1.90)[b]		
Copper	0.597	−0.089	0.16	27
	(2.47)[a]	(−2.19)[a]		

[a,b]Show 5% and 10% significance level, respectively.

The second empirical step seeks to examine hypotheses $H1$ and $H2$ separately to discover whether the interpretation of convenience yields as call options can offer an improved explanation of the variation of actual convenience yields.

The results of Table III show weak support for the Working–Brennan hypothesis. For all commodities except wheat, the level of inventory obtains a negative and significant coefficient. However, this coefficient is significant at only 5% for copper. The relatively low R^2 for all commodities along with insignificant t-statistics, suggest that other variables such as price volatility may have additional explanatory power beyond inventory levels. This is shown in next Table IV.

The results of Table IV verify the Working–Brennan hypothesis as well as the hypothesis advanced by Heinkel et al. and Milonas/Thomadakis. Indeed, for all commodities except wheat, the hypotheses that b_1 is less than zero cannot be rejected. Furthermore, the addition of the orthogonalized call option component of predicted convenience yield captures a positive and significant coefficient in all cases. This offers strong support to hypothesis $H2$. In fact, it is readily discernible that in all cases the call option component carries a much higher explanatory power than the level of inventories, since the increase in regression R^2 is dramatic. It is thus possible to conclude that call option features can contribute an important explanatory component to actual convenience yields over and above the role of inventories.

Hypothesis $H3$ predicts that convenience yields will seasonally increase as harvest approaches enabling a more accurate prediction of stockout. Convenience yields are observed once a year and at the last day of the beginning month. Convenience yields are estimated for pairs of

TABLE IV

Cochrane–Orcutt Regression Results for:
$V^A/\text{spot} = b_0 + b_1\log(I) + b_2u^* + e \quad (5)$

Commodity	b_0	b_1	b_2	R^2	*No. Obs.*
Soybeans	0.551	−0.072	0.424	0.55	28
	(3.92)[a]	(−3.47)[a]	(3.97)[a]		
Corn	0.511	−0.056	0.682	0.63	28
	(2.29)[b]	(−2.09)[b]	(5.86)[a]		
Wheat	0.326	−0.036	0.712	0.35	26
	(0.831)	(−0.67)	(3.06)[a]		
Copper	0.330	−0.052	0.078	0.65	27
	(3.71)[a]	(−3.49)[a]	(1.74)[c]		

[a,b,c]Show 1%, 5%, and 10% significance level, respectively.

consecutively maturing months in the period within the crop cycle. Table V shows the empirical results.

The results in Table V are supportive of hypothesis *H*3. First, the convenience yields as percent of contemporaneous spot prices are much greater for agriculturals than for copper. Second, agriculturals exhibit seasonal convenience yields while copper does not. For all three agriculturals, convenience yields gradually increase and become significant towards the end of the cycle and just before the new harvest. This is not the case with copper where the statistically significant convenience yields do not exhibit any time pattern within the calendar year.

Hypothesis *H*4 predicts different correlations exhibited between spot and futures prices and subsequently for futures prices of different maturity months. It is argued here that as stored inventories are affected by renewed supplies at harvest as well as by current demand, futures prices of intermediate and end-of-crop-cycle maturing contracts will be affected differently and therefore respond to demand and supply related information differently.[4] This effect will result in a smaller correlation between the two series. In contrast, for commodities with continuous production (i.e., copper), the two series of prices should be very strong and close to 1.

The correlation test is designed as follows. Two contrasts are chosen for each commodity. In the case of the agriculturals the first is the futures contract maturing in the delivery period closest to the middle of the crop year, and the second is the contract maturing in the final month of the crop year. Thus, contracts maturing in May and November are chosen

[4]The price of the contract maturing at the intermediate period will be affected by possible stockout, whereas the price of the contract maturing in the final period will not.

TABLE V

Term Structure of Convenience Yields

Commodity	*Average Convenience Yields Between Consecutive Maturing Contracts as % of Spot Price*				
Soybeans	Mar–May −.001	May–Jul −.000	Jul–Aug .009	Aug–Sep .026[a]	Sep–Nov .024[a]
Corn	May–Jul −.005	Jul–Sep .021[a]	Sep–Dec .025[a]		
Wheat	Dec–Mar −.003	Mar–May .026[a]	May–Jul .041[a]		
Copper	Mar–May .017[a]	May–Jul .013[a]	Jul–Sep .013[a]	Sep–Dec .017[a]	

Note: Convenience yields are calculated at the last day of the beginning month for each commodity shown in Table I.
[a]Indicates t-test significance of difference from zero at the 95% confidence level.

for soybeans; contracts maturing in May and December are chosen for corn; and contracts maturing in December and July are chosen for wheat. In the case of copper which has no crop cycle, two arbitrarily chosen contracts are used—one maturing in May and the other in July. Daily closing prices are collected for each contract in the four months prior to the maturity of the intermediate contract, for each year. Correlations between the daily prices of each pair of contracts are estimated for every month of observations. The means of correlation coefficients and estimation periods are shown in panel A of Table VI.

Another interpretation of hypothesis $H4$ holds that as convenience yields become larger a shortage is predicted as more likely. In that case, basically short- and long-term futures prices will increasingly fail to move together with the passage of time since short-term prices will reflect the likely shortage and long-term prices will not. This explanation can be empirically tested by estimating correlations of prices for short (intermediate month) versus long-term (final month) futures contracts in cases with high and low convenience yields. The appearance of high convenience yields should predict a reduced correlation between the futures prices. For this reason, all observations are divided into two groups, depending on the level of convenience yield *observed at the start of the cycle* between the two contracts studied. Thus, convenience yield observations are made in each year *prior* to the period of estimation of correlations between prices. Years with convenience yield above the average for the whole period are classified in the "high" group. Years with convenience yields below average are classified in the "low" group. Correlation coefficients and their means are then estimated for each group separately as before. The results of this estimation are shown in panel B of Table VI.

TABLE VI

Correlation Coefficients of Daily Prices of Intermediate and Final Month Contracts (Grains: 1972–1995; Copper: 1975–1995)

A. Overall Correlations

Commodity	*Daily Observations Between*	*No. of Monthly Correlations*	*Mean*	*St. Dev.*
Soybeans	Feb–May	96	0.86	0.15
Corn	Feb–May	96	0.76	0.20
Wheat[a]	Sep–Dec	88	0.76	0.22
Copper	Feb–May	84	0.89	0.24

B. Correlations by Convenience Yield Group

Commodity	*Conv. Yield Group*	*Mean Conv. Yield*	*Mean Corr. Coefficient*	*St. Dev.*	*t-Stat.*	*No. of Monthly Corr.*
Soybeans	Low	4.03	0.91	0.11	4.05[b]	52
	High	34.51	0.79	0.17		44
Corn	Low	−1.30	0.81	0.15	2.42[b]	48
	High	11.29	0.71	0.24		48
Wheat	Low	0.97	0.83	0.18	2.50[c]	36
	High	18.92	0.72	0.23		52
Copper	Low	0.06	0.91	0.25	1.22	64
	High	2.75	0.83	0.24		20

Note: Convenience yields are based on observations in the beginning month of the cycle.

[a]Data for wheat are not available for 1972.

[b]Statistically significant at 1.5% or better, resulting from testing the equality of correlation means between the two groups.

The results in Table VI offer strong support to hypothesis *H*4. In panel A, the price correlations are much smaller in the case of renewed commodities versus commodities with continuous production. Furthermore, the classification into a high or low convenience yield group leads to significant differences in the correlation of price of the intermediate and final futures contracts. In every case where the intermediate contract embodies high convenience yield relative to the final one in the initial period of observation, the two contracts exhibit significantly *lower* correlation in their *subsequent* price movements. In other words, the level of convenience yield observed *at the start* of the crop cycle between two contracts predicts the degree of subsequent price correlation of the two contracts *during* the cycle.

In the case of copper, no significant discrimination is shown between the two groups. This is probably due to the fact that convenience yields in the various years changed relatively little and their discriminating power is reduced as a result. As can be seen from the second column of panel B of Table VI, differences in mean yields between the two groups are quite high for agriculturals and smaller for copper.

The confirmation of hypothesis *H*4 in the case of agricultural commodities is a significant finding because it verifies the assertion that the convenience yield is a risky claim "attached" to short-term futures contracts, whose price change over time is unrelated to the price movements of a long-term futures contract which do not embody this risky claim or for whom the effect is highly diluted by other considerations. The higher the relative weight of this "attached claim," the less correlated are price movements of short- and long-term futures contracts.

SUMMARY AND CONCLUSIONS

The empirical results on four commodities studied here give strong support to theoretical models which view convenience yields as options. In the case where the commodity supply is tied to a given production cycle, adjustment costs prohibit holders from releasing inventories to keep spot and futures prices in alignment. As a result, prices will not align with each other net of storage costs. The difference corresponds to a payoff attached to claims with shorter maturity relative to claims with longer maturity. The empirical analysis shows that this payoff has the characteristics of a call option with stochastic exercise price. Furthermore, it is shown that this call option exhibits a type of term-structure which resembles seasonality within the crop cycle, as it monotonically increases with the approach of the new harvest. This behavior is consistent with the fact that the probability and the magnitude of a stockout, the primary factor which gives rise to convenience yields, increase as the crop cycle advances. In the absence of a crop cycle, a stockout either will not occur (in the case of ample supplies)[5] or if it occurs it will not be seasonal (the case of copper). Using a different set of daily price data, the correlations of two futures contracts, the intermediate month, and the final month contract are examined further. The results are supportive of lower correlations for commodities with large convenience yields (agriculturals) and larger correlations for a commodity with small or insignificant convenience yields (copper).

One major implication of the empirical results is that the call feature of convenience yields should not be ignored when tests in futures markets are sensitive to the existence of convenience yields. In this line of rea-

[5]In separate tests (not reported here) that include silver, similar results are obtained.

soning, contract maturities and dates of observations within the crop cycle should play a role in the way tests are designed for agricultural commodities. The seasonality of convenience yields within the crop cycle is bound to introduce an additional important factor is statistical tests. If this factor is not controlled, different tests may lead to contradicting evidence. Examples of such contradiction and ambiguity is the evidence on normal backwardation and risk premium, neither of which takes into account the varying behavior of convenience yields. Future empirical studies on these two issues may clear this ambiguity.

BIBLIOGRAPHY

Brennan, M. (1958): "The Supply of Storage," *American Economic Review,* 48:50–72.

Brennan, M. J. (1986): "The Cost of Convenience and the Pricing of Commodity Contingent Claims," Working Paper, UBC (revised).

Bresnahan, T., and Spiller, P. (1986): "Futures Markets Backwardation Under Risk Neutrality," *Economic Inquiry,* 24:429–441.

Fama, E., and French, K. (1987): "Commodity Futures Prices: Some Evidence of Forecast Power, Premiums, and the Theory of Storage," *Journal of Business,* 60:55–73.

Fischer, S. (1978): "Call Option Pricing When the Exercise Price is Uncertain and the Valuation of Index Bonds," *Journal of Finance,* 33:169–176.

Heinkel, R., Howe, M. E., and Hughes, J. S. (1990): "Commodity Convenience Yields as an Option Profit", *The Journal of Futures Markets,* 10:519–533.

Kaldor, N. (1939): "Speculation and Economic Stability," *The Review of Economic Studies,* 7:1–27.

Keynes, J. M. (1930): *A Treatise on Money.* New York.

Milonas, N., and Thomadakis, S. (1989): "Convenience Yield, the Option to Liquidate and Normal Backwardation," University of Massachusetts Working Paper presented at the American Finance Association Meetings, Dec. 28–30, 1989.

Telser, L. G. (1958): "Futures Treading and the Storage of Cotton and Wheat," *Journal of Political Economy,* 66:233–255.

Working, H. (1948): "Theory of the Inverse Carrying Charge in Futures Markets," *Journal of Farm Economics,* 30:1–28.

Working, H. (1949): "The Theory of the Price of Storage," *American Economic Review,* 39:1254–1262.

Wright, B. D., and Williams, J. C. (1989): "A Theory of Negative Prices for Storage," *The Journal of Futures Markets,* 9:1–13.