Is the Thinly-Traded Butter Futures Contract Priced Efficiently?

Fabien Tondel
University of Kentucky
Department of Agricultural Economics
329 C.E. Barnhart Building
Lexington, KY 40546-0276
Phone: 859-257-7272, x 280
ftond2@uky.edu

Leigh J. Maynard
University of Kentucky
Department of Agricultural Economics
319 C.E. Barnhart Building
Lexington, KY 40546-0276
Phone: 859-257-7286
lmaynard@uky.edu

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ABSTRACT

After over eight years of trading, the Chicago Mercantile Exchange butter futures contract remains thinly traded, possibly impeding price discovery. Pricing efficiency was assessed using cointegration techniques and error correction models. Results suggest that market efficiency could not be rejected up to a two-month forecast horizon. Illiquid markets reduce hedging performance, which in turn discourage liquidity growth.

INTRODUCTION

The decline of Federal government milk and butter price support in the 1990's, coupled with substantial price volatility in the butter cash market created a propitious environment for establishing of a butter futures market. In 1996, the Chicago Mercantile Exchange (CME) introduced a butter futures contract to provide dairy and food industries with a solution for facilitating price discovery and price risk management. Butter futures contracts had previously traded at the CME since 1919. However, heavy government intervention in butter pricing, especially through public stockholding, protected market agents from low price risk and hindered participation in futures trading (Manchester and Blayney, 2001). Despite the well established cash market at the CME and the specific characteristics of the underlying commodity (homogeneity, storability and continuous production), the butter futures market remained thinly traded since its inception. Over the past years, daily open interest of the butter futures market has not surpassed 2,000 contracts while trading volume did not usually exceed 200 contracts. The butter futures market is much less large and liquid than grain futures markets whose daily open interest and trading volume often exceed 200,000 and 50,000 contracts, respectively. Although there has been a significant upward trend towards greater participation in the butter futures market from 2001 through 2003 – trading was up 329.2% in 2002 (DeGrand, 2003) – participation is still low.

The concentration of the butter industry is probably one of the reasons why the futures market is thin and liquidity is low. Gray (1960) explained that a thin futures market is more likely to be unbalanced and inefficient than a larger market. Pricing inefficiency in the butter futures market may be another reason for low participation. Indeed, the hedging effectiveness of a futures market is dependent upon the extent to which futures prices provide unbiased estimates of cash prices at contract expiration. If the market fails to price efficiently, then the contract will be less attractive to hedgers willing to manage butter cash price risk.

The main objective of this paper is to assess the price forecasting function of the butter futures market. Cointegration techniques are used along with error-correction models to test for market unbiasedness and efficiency. The first section of the paper addresses the notion of futures market efficiency. The second section presents the methodology to test for market efficiency. The third section describes the data and exposes the empirical results. Lastly, the conclusion discusses implications of results for the use of the futures market as a price discovery and risk management tool.

FUTURES MARKET EFFICIENCY

The hypothesis of futures market efficiency is a straight application of the Efficient Market Hypothesis (EMH) as defined by Fama (1970). Market prices efficiently if asset prices – futures contract prices for instance – account for all relevant accessible contemporary information. Thus, if the market is efficient the asset price is an unbiased estimate of its intrinsic value. Market efficiency tests fall into three categories depending on the type of information relevant to asset pricing. Weak-form efficiency tests examine whether contemporary prices account for all information contained in past market prices. Semi-strong-form tests assume all publicly accessible information. Strong-form tests assume all publicly and privately accessible information. In this study, we will test for the weak-form efficiency of the butter futures market. According to the EMH, price changes reflect new information, which is randomly generated, and hence, prices follow a random walk: $FP_t = FP_{t-1} + \varepsilon_t$, where FP_t is the futures price at time t, FP_{t-1} the futures price the period before and ε_t a white noise error term.

The hypothesis of futures market unbiasedness is a particular case of Fama's weak-form efficiency. The Unbiased Market Hypothesis (UMH) implies that the current futures price is an unbiased estimate of the cash price underlying the same asset, at contract maturity. Let CP_t be the cash price of a commodity at time t, FP_{t-i} be the price of a futures contract at time $t-i$, i periods prior to its expiration. For the purpose of exposition, consider $i = 1$. The UMH can be stated as follows[1]: $CP_t = FP_{t-1} + \varepsilon_t$. A common approach to test for the UMH, or market efficiency in a broader sense, is to regress CP_t on FP_{t-1} as in equation (1) below, and then test for the null hypothesis that the intercept α is zero and the slope β is unity:

$$CP_t = \alpha + \beta FP_{t-1} + \varepsilon_t \tag{1}$$

where ε_t is a rational expectations error with the properties of a zero mean and a constant variance. Assuming the futures market is competitive and hedging is optimal, the non-

[1] Let $E_t[...] = E[.../I_t]$ denote the mathematical expectation conditional on the information set I_t available to economic agents at time t. If market participants are endowed with rational expectations, the futures price can be thought of as differing from the expected future cash price by a rational expectations forecast error $\varepsilon_{1,t}$: $FP_{t-1} = E_{t-1}[CP_t] + \varepsilon_{1,t-1}$.(i) The actual realization of CP_t will differ from the expected level by a rational expectations forecast error $\varepsilon_{2,t}$: $CP_t = E_{t-1}[CP_t] + \varepsilon_{2,t}$.(ii). The UMH is then obtained from substituting (i) into (ii).

rejection of the null hypothesis would lead to conclude that FP_{t-1} is an accurate forecast of CP_t. Following this approach, Kofi (1973) studied the forward pricing function of agricultural futures markets (cocoa, coffee, corn, etc.) and showed that the correlation coefficient, R^2, is a reliable measure of the degree to which futures prices forecast cash prices months in advance. The forecasting precision of a futures market improves as traders obtain more accurate information on supply and demand at contract expiration. Tomek and Gray (1970) outlined basic differences in intertemporal price relationships between futures markets for commodities with continuous inventories (corn and soybeans) and markets for commodities with discontinuous inventories (potatoes). The forward pricing function of futures markets is more reliable for the latter rather than for the former. Leuthold (1974) examined the forward pricing function of the thinly-traded contract for live beef cattle. He showed that futures prices for live beef cattle estimate subsequent cash prices as efficiently as do corn futures prices up to a four-month forecast horizon. At distant horizons, the cash price is a more accurate estimate of the future cash price than is the futures price.

More recent studies in futures commodity and financial futures markets invalided efficiency tests based on (1) and alternative methods were implemented. A first criticism bears upon the nature of the stochastic process underlying futures and cash prices series. Granger and Newbold (1974) showed that if the data series under consideration are nonstationary, the standard errors are highly misleading. Regression of one nonstationary series on another one may produce a unit root in the error series, a low Durbin-Watson statistic, a high R^2, high t- and F-statistics even when the two are, in fact, independent. Second, as Beck (1993) pointed out, the UMH is a joint hypothesis of market efficiency and the absence of a risk premium. Rejection on the null hypothesis on the parameters of (1) can be interpreted as either the futures market is inefficient or there is a risk premium. Futures markets containing a risk premium would be biased, but could still price efficiently. Moreover, the hypothesis that $\alpha=0$ is not consistent with the theory of normal backwardation (Keynes, 1930) and the theory of intertemporal hedging (Danthine, 1978) predicts that $\alpha\neq0$ and $\beta\neq1$. Third, McKenzie *et al.* (2001) mentioned that market unbiasedness over a long period of time (several years) does not preclude deviations from the long-run relationship between futures and cash prices over shorter period of time (several weeks or months). The next section will present the method to test for the UMH and the EMH in the butter futures market.

METHODOLOGY

Cointegration techniques have been applied by Hakkio and Rush (1989) to test unbiasedness in foreign exchange markets, by Chowdury (1991) to test unbiasedness in the metal markets at the London Metal Exchange and by Beck (1994) to test market efficiency in agricultural futures markets. Following the definition of Engle and Granger (1987), futures and cash prices series are said to be cointegrated of order (x, y), if both series are $I(x)$[2] and there exists a vector $(1, -\beta)$ such that $(1, -\beta)`(CP_t, FP_{t-1})$ is $I(x - y)$, y being greater than zero. $(1, -\beta)$ is called the cointegrating vector. Cointegration of order $(1, 1)$ will be investigated in this study. Thus the series are cointegrated if they are $I(1)$, i.e., if they can be made stationary by differencing them once, and if $\varepsilon_t = CP_t - \alpha - \beta FP_{t-1}$ is a stationary error series; $(1, -\alpha, -\beta)$ is the cointegrating vector that includes an intercept term. The cointegrating relationship implies that CP_t and FP_{t-1} keep in line with each

[2] A series with no deterministic trend which has a stationary, invertible, autoregressive moving average representation after differencing x times, is said to be integrated of order x, or $I(x)$.

other and that the latter is an unbiased estimate of the former. Furthermore, if CP_t and FP_t are cointegrated, then they share at least a common stochastic trend or random walk (Stock and Watson, 1988). Since the same fundamentals are reflected in both prices, cointegration implies that the same information that is incorporated in futures prices is also reflected in subsequent cash prices. Therefore, futures and cash prices cointegration suggests that the market prices efficiently.

Cointegration between futures and cash prices is a necessary but not sufficient condition for market weak-form efficiency. Contemporaneous futures prices may be cointegrated with cash prices at maturity, but prior futures and cash prices may contain additional information improving futures price forecasts. According to the Granger representation theorem (Engle and Granger, 1987) two cointegrated time series, such as futures and cash prices, can be rewritten in an Error Correction Model (ECM) specified as follows:

$$\Delta CP_t = \delta - \rho\varepsilon_{t-1} + \pi\Delta FP_{t-1} + \sum_{i=1}^{m}\phi_i \Delta CP_{t-i} + \sum_{i=1}^{n}\gamma_i \Delta FP_{t-1-i} + \nu_t \qquad (2)$$

where Δ is the difference operator, ε_{t-1} is the error-correction term from (1), and ν_t is a stationary, possibly serially correlated series with zero mean. In the ECM, a proportion of the disequilibrium ε_{t-1} from one period is corrected in the next period. Lagged terms permits any delayed adjustment toward a new equilibrium. Hence, the ECM allows futures and cash prices to obey equilibrium constraints (as specified in (1)) without precluding short-run deviations from the long-run relationship. In this regard, the parameter of ε_{t-1} may be considered as a measure of the speed of adjustment to the equilibrium.

The ECM representation makes the series *I(0)* and statistical tests based on OLS estimates suitable. If the UMH restrictions on (1) that $\alpha=0$ and $\beta=1$ hold, then the restrictions of market unbiasedness on the ECM are determined by substituting

$CP_{t-1} - \alpha - \beta FP_{t-2}$ for ε_{t-1} from (1) and rewriting (2) as following (equation (3)):

$$CP_t = \delta + (1+\rho)CP_{t-1} + \pi FP_{t-1} - (\rho\beta + \pi)FP_{t-2} - \rho\alpha + \sum_{i=1}^{m}\phi_i \Delta CP_{t-i} + \sum_{i=1}^{n}\gamma_i \Delta FP_{t-1-i} + \nu_t$$

Upon the condition that $\alpha=0$ and $\beta=1$, market unbiasedness requires the restrictions $\rho=-1$, $\pi=1$, and $\varphi_i=\gamma_i=0$ from equation (3) to hold. Consistent with the EMH, coefficients of lagged cash and futures prices changes, φ_i and γ_i, should be zero because past information is already fully reflected in the current futures price. For the same reason, market efficiency also implies v_t is serially uncorrelated. If the additional restrictions $\rho=-1$, $\pi=1$, and $\varphi_i=\gamma_i=0$ hold along with the restrictions, $\alpha=0$ and $\beta=1$, equation (3), is consistent with the cointegrating relationship (1). Furthermore, the approach developed by Beck (1994) allows one to distinguish the pricing efficiency and risk premium components in the price forecasting function. The alternative testing hypothesis $\rho=-1$, $\pi=\beta$, and $\varphi_i=\gamma_i=0$ does not impose the restriction $\alpha=0$ and $\beta=1$. Thus, market efficiency can be tested independently of the presence of risk premia.

DATA AND EMPIRICAL RESULTS

Data

The data used in this study consist of daily butter futures prices from the CME, which are sampled on a monthly basis over the period 1997-2003, and weekly grade AA butter cash prices. A first cash price series consists of the weekly average CME cash price. A second cash price series is constructed using the National Agricultural Statistics Service

(NASS) price, which is available only from October 1998. The NASS price is a weekly weighted average price received for U.S. sales of bulk grade AA butter packed in boxes of 25 kilograms or 68 pounds[3]. NASS prices were obtained from the *Dairy Market News* reports published by the Agricultural Marketing Service. Since the butter futures contract settles through physical delivery, a third cash price series was constructed with futures prices at contract expiration[4]. CME futures and cash prices were obtained from the website of the University of Wisconsin-Madison – "Understanding Dairy Markets" (December 2003). Futures contracts pooled range from the June 1997 contract to the December 2003 contract. However, butter futures contract specifications have not been constant over the period 1997-2003. In 1997, the six contracts traded were the February, April, June, July, September and November contracts. The following year, the April, June and November contracts were replaced by the March, May and October contracts. In 2001, a December contract substituted for the February contract.

Following Kofi (1973), efficiency tests were conducted using a single observation a year for each contract at forecast horizons ranging one to six months[5]. Pooling all contracts does not allow us to determine the degree to which efficiency differed across contract months. Moreover, when the forecast horizon is longer than the observation interval, overlapping observations generate a moving average process in the residuals of (1) (Granger and Newbold, 1977, p. 115). Residual autocorrelation result in inefficient OLS estimates. Given the small size of price series, due to the short existence of the

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[3] The NASS cash price is the first estimate of the average price at which transactions occurred during the week the futures contract expired. Updated price estimates released in *Dairy Markets News* are not used.
[4] Theoretically, the futures price at expiration and the cash price are equal since arbitrage will drive them together. In practice, using futures prices may avoid biases due to failure in the arbitrage process.
[5] Futures prices are daily closing prices of trading days corresponding to the expiration day (eight-to-last business day of the month). For instance, the March 2003 contract expired on the 20th of March; futures prices were picked up on the 20th (or the following business day) of February, January, December, etc.

butter futures market, we could not perform valid statistical tests on each individual contract separately or on a sub-sample of non-overlapping contracts.

Empirical Results

OLS Level Regressions – Tests of Market Unbiasedness

The results for the UMH tests based on (1) are summarized in table 1. R^2 values become lower as the forecast horizon lengthens. R^2 values also suggest that the market performs slightly better its price forecasting function with respect to the futures contract settlement price rather than the CME cash price. Comparison with the NASS price regressions is subject to false statements since there are missing values for 1997 and 1998 in the NASS price series. However, the futures price could be a better forecast of the average price at which trades occur in local cash markets rather than the CME cash price. A comparison of the R^2 values from the CME cash price regressions with R^2 values from previous studies on agricultural commodities markets is presented in table 2. The price forecasting function of the butter futures market looks very similar to the one of discontinuous inventory commodity markets for live beef cattle and potatoes rather than the one of the corn and wheat markets. Furthermore, the butter futures market performance decreases even faster compared to the cattle and potatoes futures as one gets farther away from expiration.

The UMH is never rejected at the 5% level of significance for the futures settlement price while it is rejected only at the 6-month horizon for the CME cash price. The market unbiasedness hypothesis is rejected the 1-, 4- and 5-month horizons for the NASS price. The pattern of the R^2 value over the contract life (up to six month prior to maturity) and the rejection of the UMH at a six-month horizon suggest that the market fails to establish intertemporal price relationships beyond five months away from maturity. Supply shocks and demand changes for butter may actually be unpredictable five or six months in advance. Indeed, supply and demand for butterfat are highly seasonal and are dependent upon the seasonality of milk production (quantity, quality) and the annual schedule of demand for dairy food products such as ice cream. Hence, the seasonal pattern of butter fundamentals may impede efficient price discovery in the futures market. However, Elam and Dixon (1988) showed that nonstationarity and small sample size lead to biased results towards the rejection of the null hypothesis of market unbiasedness when using the F-test. As mentioned above, the correlation between futures and cash prices may also be overstated due to nonstationarity in the series. Thus, results obtained from level regressions should be interpreted with prudence because price series may contain a unit root and the number of observations is small. In the next section, the 1-, 2-, 3- and 4-month price series and the CME cash price series are retained to further examine the efficiency of the butter futures market.

The computation of the average basis (CME cash price at expiration minus futures price) up to six months away from expiration (table 3) suggests that the market is downward biased on the average and to a greater extent as one gets farther from maturity. Thus, risk premia may prevail in the butter futures market. Besides, the rejection of the null hypothesis at the nearby horizon for the NASS price might be explained by a significant negative basis (-2.09 cents, t-statistic = -2.47). Prices at which local transactions occur are likely to be lower than CME prices because they do not include transportation costs to CME approved delivery points. In addition, the CME price is considered as a benchmark for local markets; thus, it probably leads the NASS price.

Stationarity diagnostic tests

The Augmented Dickey-Fuller (ADF) test (Dickey and Fuller, 1979, 1981) and Phillips-Perron (PP) test (Phillips and Perron, 1988) were used to determine whether price series contain a unit root, or (equivalently) if they are *I(1)*. Both tests were performed on two autoregressive model specifications, (i) without constant term, and (ii) with constant term[6]. The lag specification of both model is chosen from the data using the Lagrange multiplier statistics. One and three lags are added to the models for the cash price and the 1-month futures price series, respectively. None of the other futures price series require any lag term to remove residual autocorrelation. The PP test uses nonparametric methods to cope with possible autocorrelation in the error term but its asymptotic distribution is the same as the ADF test statistic. The null hypothesis of those unit roots tests is that the series has a unit root. Unit root tests results are reported in table 4. The ADF τ-test for the specification with constant term led to reject, at the 5% level of significance, the null hypothesis that the CME cash price series has a unit root although PP τ-test did not. However, it was not rejected at the 1% level and differencing the series led to reject the null hypothesis of a unit root with both the ADF and PP tests. Therefore, in the following analysis, we will make the reasonable assumption that the CME cash price series behaves as a *I(1)* stochastic process. ADF and PP tests suggest that the hypothesis of a unit root cannot be rejected for the 1-, 2-, 3- and 4-month futures price series; differencing once the series led to reject the null hypothesis of nonstationarity. Hence, price series behave like *I(1)* stochastic processes. The fact that price series contain a unit root and may be described as random walks is an argument in favor of market

[6] A stochastic trend term is not deemed to be included in the AR model because the time period under consideration is short (less than 7 years) and price series are not likely to be time trended.

weak-form efficiency. Furthermore, futures and cash prices meet of one the necessary conditions for cointegration of order *(1, 1)*.

Cointegration tests

Cointegration of order *(1, 1)* between *CP* and *FP* is tested for with two methods. First, the Engle-Granger two-step estimation procedure is implemented. The cointegrating regression (1) is estimated by the Yule-Walker estimation method. Residual series are then tested for stationarity using the Phillips and Ouliaris (1990) (PO) unit root test. Results of the unit root test on residuals are reported in table 5. The null hypothesis of no cointegration is rejected at the 5% level at the 1- and 2-month horizons. It is rejected at the 10% level at the 3- and 4-month horizons. Further cointegration testing is carried out using the method developed by Johansen (1988) and Johansen and Juselius (1990). The Johansen and Juselius procedure is a multivariate approach based on deriving maximum likelihood estimates of the cointegrating regression. Results are reported in table 6. The trace and maximal eigenvalue (λ_{max}) statistics for the null hypothesis of no cointegration and the null of cointegration rank at most equal to one, at the 5% (10%) level, led to conclude that the 1- and 2-month (4-month) futures prices are cointegrated with the cash price. The λ_{max} statistics led to fail to reject the null of no cointegration at the 3-month horizon.

Error Correction Model Estimation

Since the error correction representation requires the series to be cointegrated, ECMs were estimated using the 1-, 2- and 4-month futures prices only. For each horizon, two ECMs were estimated. A first ECM was estimated with the lagged error term recovered from the restricted ($\alpha=0$, $\beta=1$) cointegrating regression (1). A second ECM was estimated with the lagged error term from the unrestricted cointegrating regression, and thus, without intercep. Following Engle and Granger, ECMs were initially estimated with zero to six lags of ΔCP_t and ΔFP_{t-1}. None of the lag term coefficient estimates was found to be significant in all ECMs, suggesting that the market prices efficiently. Residual diagnostic checks show no evidence of autocorrelation. The Lagrange multiplier test for autoregressive conditional heteroscedasticity (ARCH) disturbances revealed a second order ARCH process in the 4-month residual for both ECM specifications, which violates the EMH.

The ECM specification based on the market unbiasedness restriction on (1) allows one to test for market unbiasedness. The Wald test led to fail to reject the null hypothesis of market unbiasedness at the 1- and 2-month horizons but rejected it at the 4-month horizon. The null hypothesis of market efficiency could not be rejected at 1- and 2-month horizons on the basis the Wald test for the restrictions on the ECM incorporating the non-restricted long-run relationship between futures and cash prices. It was rejected at four months. In every case, coefficient estimates are consistent with cointegration results. Coefficient estimates of the futures price change are close to 1, thus providing evidence for market unbiasedness. Changes in futures price actually respond to changes in subsequent cash price in such a way that the former are reliable estimates of the latter. Coefficient estimates of the error term are very close to -1 at one month but decrease in absolute value as one move to the farther horizons. This finding suggest that the speed of adjustment to the equilibrium relationship between futures and cash prices after a deviation is higher at nearby horizon and instantaneous at one month.

CONCLUSION

The statistical analysis performed in this study brought some pieces of evidence to answer the initial question: “Is the thinly-traded butter futures contract priced efficiently?” Level regressions indicated that the butter futures market provides unbiased forecasts of CME cash prices up to 5 months away from expiration although it is likely biased at distant horizons. Cointegration tests provided additional evidence to support the efficiency of the butter futures market at short horizons – one and two month – and to a lesser degree at longer horizons – three and four months. Additional tests for the UMH and the EMH allowed by using an ECM specification led to conclude that the butter futures contract is priced efficiently up to a two-month horizon, but it fails to impound information from past prices about future supply and demand conditions efficiently. However, the conclusion drawn upon from those results are subject to the small sample size of price data. As more data become available, test of market efficiency at longer horizons should be performed.

As a matter of fact, the butter futures market seems to behave like a market for a non-storable commodity. This finding has important implications for the use of the contract as a risk management instrument as well as a medium of price discovery. First, uncertainty about supply and demand conditions at contract maturity is certainly elevated in the butter market. Second, continuous production and preference for “fresh” butter explain that although butter is storable, its storability and the guidance of inventory differ from commodities like grains. Third, lack of participation in futures contract trading, in terms of hedging and speculation, may impede the market to price efficiently beyond the 2- or 3-month horizons. Imbalance hedging at distant horizons is also likely to generate substantial risk premia and biased futures prices. Therefore, long hedges are unlikely to protect against price risk and to stabilize input outlays or incomes. The market would also fail in helping optimal resource allocation planning at distant horizons. The butter futures market would need to be promoted in order to increase its size and liquidity and to improve its price discovery function. The replacement of physical delivery by a more flexible cash settlement procedure would be a strategy to consider in order to attract potential participants in the market, especially those like ice cream manufacturers, who need to hedge their butterfat input (or output in some cases).

Mixed results concerning the efficiency of the butter futures market do not deny at all the usefulness of this pricing institution. In the futures industry, commonly used criteria of performance are based on the open interest and trading volume levels. The recent rise of participation in butter futures do not preclude a promising future for this market even though heavy government regulation still prevails in dairy product pricing. The development of futures markets is perceived as a positive step in the butter and dairy industry.

Table 1. OLS level regressions

Month lag	α [a]	β [a]	R^2	F [b]
CP: Futures price at expiration				
1	12.49	0.91	0.76	0.59
	(11.50)	(0.08)		
2	7.02	0.98	0.55	0.68
	(19.25)	(0.14)		
3	14.70	0.92	0.45	0.55
	(22.28)	(0.17)		
4	56.87	0.60	0.15	1.83
	(30.92)	(0.24)		
5	76.44	0.46	0.08	2.72
	(34.94)	(0.27)		
6	95.68	0.31	0.03	2.93
	(43.57)	(0.34)		
CP: CME cash price				
1	13.14	0.91	0.75	0.61
	(12.07)	(0.09)		
2	9.25	0.97	0.52	0.84
	(20.10)	(0.15)		
3	16.75	0.91	0.43	0.70
	(22.97)	(0.17)		
4	61.11	0.57	0.13	2.09
	(31.25)	(0.24)		
5	84.33	0.40	0.06	3.19
	(35.41)	(0.28)		
6	104.15	0.25	0.02	3.42*
	(43.79)	(0.34)		
CP: NASS cash price				
1	19.59	0.81	0.84	7.12*
	(9.12)	(0.07)		
2	12.24	0.87	0.62	1.17
	(17.19)	(0.13)		
3	14.41	0.85	0.54	1.56
	(19.54)	(0.14)		
4	45.85	0.59	0.29	4.42*
	(23.08)	(0.17)		
5	56.64	0.51	0.18	3.66*
	(27.61)	(0.21)		
6	74.66	0.38	0.07	2.89
	(35.64)	(0.27)		

[a] Standard error estimates of α and β are provided in parentheses.

[b] F is the F-test for the joint null hypothesis $\alpha = 0$ and $\beta = 1$. Critical values of the F-test at the 10%, 5% and 1% level of significance, for (2, 40) d.f., are 2.44, 3.23 and 5.18, respectively.
* Indicates significance at the 5% level.

Table 2. Compared R^2 values

Month lag	Butter	Live beef cattle [a]	Potatoes [b]	Corn [a]	Wheat [b]
1	0.75	0.85	0.71	0.78	0.90
2	0.52	0.57	0.70	0.76	0.83
3	0.43	0.41	0.61	0.49	0.78
4	0.13	0.28	0.31	0.27	0.72
5	0.06	0.16	0.14	0.15	0.67
6	0.02	0.10	0.06	0.06	0.65

[a] Leuthold, 1973.
[b] Kofi, 1973.

Table 3. Average CME basis 0 to 6 months prior to contract expiration

Month lag	Basis mean (cents/lb)	Std error
0	0.78	0.51
1	1.47	3.27
2	5.76	4.42
3	5.25	4.87
4	5.55	6.02
5	8.04	6.75
6	10.00	7.28

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Table 4. Augmented Dickey-Fuller and Phillips-Perron unit root tests

Series	τ-test	No constant, no time trend specification [a]	Constant, no time trend specification [b]
		CME cash price	
CP	ADF	-0.64	-3.24*
	PP	-0.61	-2.77
ΔCP	ADF	-4.87*	-4.81*
	PP	-5.33*	-5.26*
		1-month futures price	
FP	ADF	-0.44	-2.25
	PP	-0.52	-2.45
ΔFP	ADF	-3.11*	-3.06*
	PP	-5.69*	-5.61*
		2-month futures price	
FP	ADF	-0.39	-2.54
	PP	-0.36	-2.58
ΔFP	ADF	-6.61*	-6.52*
	PP	-6.61*	-6.52*
		3-month futures price	
FP	ADF	-0.46	-2.45
	PP	-0.44	-2.49
ΔFP	ADF	-6.66*	-6.58*
	PP	-6.66*	-6.57*
		4-month futures price	
FP	ADF	-0.41	-2.25
	PP	-0.43	-2.39
ΔFP	ADF	-5.58*	-5.50*
	PP	-5.58*	-5.50*

Δ: first difference operator.
[a] Critical values of the ADF and PP τ-test at the 1% and 5 % level of significance are –2.62 and –1.95, respectively, according to Dickey and Fuller (1979, 1981) and Phillips and Perron (1988).
[b] Critical values of the ADF and PP τ-test at the 1% and 5 % level of significance are –3.58 and –2.93, respectively.
* Indicates rejection of the null hypothesis of a unit root at the 5 % level of significance.

Table 5. Engle and Granger cointegration procedure

Month lag	Cointegrating vector α	Cointegrating vector β	PO Z-test [a]	PO τ-test [b]
1	13.14	0.91	-32.40**	-5.20**
2	9.25	0.97	-26.35*	-4.46**
3	16.75	0.91	-17.97º	-3.34º
4	61.11	0.57	-19.99º	-3.61*

[a] Critical values of the Z-test at the 1%, 5% and 10% levels of significance are –28.3218, –20.4935 and –17.0390, respectively.
[b] Critical values of the τ-test at the 1%, 5%, and 10% levels of significance are –3.9618, –3.3654 and –3.0657, respectively. For each test, the null hypothesis of no cointegration is rejected when the computed value of the test statistic is smaller than the critical value.
** Indicates rejection of Ho: no cointegration, at the 1% level. * Indicates rejection of Ho: no cointegration, at the 5% level. º Indicates rejection of Ho: no cointegration, at the 10% level.

Table 6. Johansen and Juselius cointegration procedure

Month lag	Cointegrating vector α	Cointegrating vector β	JJ-MLE Trace r = 0 [a]	JJ-MLE Trace r <= 1 [b]	JJ-MLE λ_{max} r = 0 [c]	JJ-MLE λ_{max} r <= 1 [d]
1	-35.38	-0.75	22.49*	5.98	16.51*	5.98
2	-47.25	-0.68	22.94*	6.73	16.21*	6.73
3	-50.62	-0.65	30.13**	10.33	19.80	10.33
4	-21.05	-0.88	37.77**	10.33	27.45**	10.33

[a] Critical value at the 5% (1%) level of significance: 19.99 (24.74). [b] Critical value at the 5% (1%) level of significance: 9.13 (12.73). [c] Critical value at the 5% (1%) level of significance: 15.67 (20.20). [d] Critical value at the 5% (1%) level of significance: 9.24 (12.97).
* (**) Indicates rejection of the null hypothesis on the cointegration rank *r* at the 5% (1%) level.

Table 7.1. ECM estimation – Restricted cointegrating vector : $e_{t-1} = CP_t – FP_{t-1}$ [b]

Month lag	Estimated model [a]	R²	W [b]	DW [c]
1	$\Delta CP_t = 1.14 – 0.99e_{t-1} + 1.16\Delta FP_{t-1}$ (3.37) (0.21) (0.16)	0.58	1.60	2.07
2	$\Delta CP_t = 3.71 – 0.66e_{t-1} + 0.90\Delta FP_{t-1}$ (4.56) (0.21) (0.26)	0.27	3.55	2.02
4	$\Delta CP_t = 3.38 – 0.50e_{t-1} + 0.91\Delta FP_{t-1}$ (5.69) (0.20) (0.42)	0.16	9.78*	1.87

[a] Standard error estimates of the parameters are reported in parentheses.
[b] W is the Wald test for the market unbiasedness restrictions: ρ = -1, π = 1 and φi = γi = 0. Critical values of the test at the 10% and 5% level of significance, for 2 d.f., , are 4.60 and 5.99, respectively.
* Indicates significance at the 5% level.

Table 7.2. ECM estimation – Unrestricted cointegrating vector : $e_{t-1} = CP_t - \alpha - \beta FP_{t-1}$

Month lag	Estimated model [a]	R^2	W [b]	DW
1	$\Delta CP_t = -0.99e_{t-1} + 1.11\Delta FP_{t-1}$ $(0.20) \quad (0.15)$	0.60	2.74	2.14
2	$\Delta CP_t = -0.65e_{t-1} + 0.89\Delta FP_{t-1}$ $(0.20) \quad (0.26)$	0.27	3.88	2.02
4	$\Delta CP_t = -0.63e_{t-1} + 0.94\Delta FP_{t-1}$ $(0.17) \quad (0.36)$	0.27	12.16*	1.90

[a] Standard error estimates of the parameters are reported in parentheses.
[b] W is the Wald test for the market efficiency restrictions: $\rho = -1$, $\pi = \beta$ and $\varphi i = \gamma i = 0$ (critical values: see table 7.1).
* Indicates significance at the 5% level.

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