BUBBLES IN COMMODITIES MARKETS

by

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Abstract

We investigate the presence of rational speculative bubbles in 28 commodities traded in the U.S. markets. Using the duration dependence test on the stochastic interest-adjusted basis, we find that 11 of 28 commodities experienced some episodes of rational speculative bubble. These commodities are in the energy sector WTI crude oil; in foodstuffs and industrials sector coffee; in livestock and meats sector lean hogs; and in metals gold and platinum. In the grains and oilseeds sector corn, the soybean sub-sector (soybean No.2, soybean meal and oil) and the wheat sub-sector,(wheat No.2 soft red and hard winter) all exhibited speculative bubbles Additionally, we report mean reversion in natural gas, propane, live cattle, and pork bellies.

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I. Introduction

Historically, consistently positive excess returns in asset markets have indicated speculative bubbles. In the last several years, investing in commodities has offered spectacular and consistently positive returns to investors. This suggests the possible existence of rational speculative bubbles: although investors realize that traded assets are overvalued, they are not willing to close out their positions, because they believe that higher prices will compensate them for the increased risks of the bubble deflating. Our study explores whether such behavior exists in commodity markets.

This topic is timely. In the September 2006, the International Monetary Fund published its World Economic Outlook where it dedicated a chapter on the influence increased commodity prices have on the global economy. Speculation in commodities, in particular the energy, ferrous metal and precious metal sectors, are believed to have contributed to a sizeable increase in the commodity prices, Antoshin and Samiei, 2006. Moreover, the United States Senate Permanent Subcommittee on Investigations in a report released on June 27, 2006, "The Role of Market Speculation in Rising Oil and Gas Prices"; found evidence for speculative pressures in the energy sector, in particular around Hurricane Katrina in 2005. Also, Commodities and Futures Trading Commission has been expected to release an extensive report on the presence of speculation in commodities futures markets. According a Reuters story, retrieved using their publicly available news service, the CFTC received in excess of 6,000 emails and comments from traders on speculation in commodities markets. The implications are wide from policy, regulatory and investment perspectives. Finally, the 2006 collapse of Amaranth Advisors LLC, a hedge fund, is largely and widely attributed to speculation in commodities – natural gas – futures. [2]

Our study focuses on rational speculative bubbles in commodities markets and tests for the existence of these types of bubbles on 28 widely traded commodities in energy[3], foodstuffs and industrials[4], grains and oilseeds[5], livestock and meats[6], to metals[7]. A rational expectations bubble is characterized by negative duration dependence: as prices are continuously are bid up by investors, the probability that positive excess returns would continue into subsequent periods, decreases with the length of positive excess returns. Conversely, the probability that negative excess returns would replace the consistent positive excess returns should be an increasing function of the length of positive excess returns, or negative duration dependence.

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2 The investigative report "Excessive Speculation in the Natural Gas Market" by United States Senate Permanent Subcommittee on Investigations, dated June 25, 2007, found that Amaranth's actions caused "significant price movements in the natural gas market [that] demonstrate[s] that excessive speculation distorts prices, increases volatility, and increases costs and risks for natural gas consumers, such as utilities, who ultimately pass on inflated costs to their customers". On July 25, 2007, the U.S. Commodity Futures Trading Commission (CFTC) filed a lawsuit against Amaranth Advisors alleging "a scheme of price manipulation", specifically "manipulate the price of natural gas futures contracts on the NYMEX on February 24 and April 26, 2006"

3 Crude Oil, Brent/Global Spot, Crude Oil WTI/Global Spot, Gasoline, Unleaded Gas/Regular Non Oxygenated, Heating Oil#2/Fuel Oil, Natural Gas, Henry Hub, and Propane

4 Butter, Aa grade, Coffee, Cotton/1-1/16".

5 Barley, Western/No. 1, Corn/No. 2 Yellow, Flaxseed/No. 1, Soybean/No. 2 Yellow, Soybean Meal/48% Protein, Soybean Oil/Crude, Wheat/No. 2 Soft Red, Domestic Feed/No. 3, and Wheat/No. 2 Hard Winter.

6 Cattle, Feeder/Average, Cattle, Live/Choice Average, Hogs, Lean/Average Iowa/Small, Pork Bellies, and Frozen 12-14 lbs.

7 Copper/High Grade, Gold, Palladium, Platinum, and Silver.

We apply the McQueen and Thorley (1994) non-parametric duration dependence test, an approach that previously has successfully identified rational speculative bubbles in the equity, currency and real estate markets[8], on the interest-adjusted basis. The interest-adjusted basis captures the speculative potential in commodities (eg., Fama and French, 1988; Ludkovski and Carmona, 2004; and Casassus and Collin-Dufresne, 2005) [9]. To estimate the interest-adjusted basis, we first match contiguous physical spot prices for each of the 28 commodities with a maturity invariant index of financial futures time series, and then adjust for both the risk-free rate and the stochastic convenience yield. We then subject the interest-adjusted basis to the duration dependence test to assess the likelihood of negative duration dependence [10].

The study offers two main contributions to literature. *First*, the study expands the literature of rational speculative bubbles to commodities markets. *Second*, it addresses

8 Using the duration dependence test, Chan, McQueen and Thorley (1998) found no evidence of rational speculative bubble in the any of seven Asian stock markets. Lavin and Zorn (2001) applied the duration dependence technique on Iowa and Nebraska land value but found no evidence of rational expectations bubbles. Jiraskuldech et al (2006) applied duration dependence test and confirmed the existence of rational speculative bubbles in the USD/GBP exchange rate.

9 There are two somewhat dissimilar definitions of the interest-adjusted basis in the literature. Fama and French (1988) define the interest-adjusted basis as $\frac{F_{i,tT} - S_{i,t}}{S_{i,t}}$, where $F_{i,tT}$ is the price of the futures contract on the commodity maturing at T at time t, where $t < T$, and S_{it}, is the spot price of the commodity at t. Heaney (2002) defines the interest-adjusted basis as $\mathrm{f}_{\mathrm{i,tT}} - s_{i,t} - r_{f,tT} - c_{tT}$, where $f_{i,tT}$ is the log of the price of the futures contract on the commodity at time t maturing at T, and s_{it}, is the log of the spot price of the commodity at t, $r_{f,tT}$ is the prevailing risk-free rate between t and T, and c_{tT} is the convenience yield between t and T, where $t < T$. We consider this interest-adjusted basis as a measure for excess return.

10 Negative duration dependence implies that the probability of the positive runs ending and the length of the runs are negatively related, i.e., the longer the positive run, the less likely it is to convert to a negative run.

some methodological shortcomings in empirical tests previously used to detect speculative behavior in financial markets.

The study expands the literature on speculative behavior in commodities. Only one previously published study tests for the possible presence of rational bubbles in any commodity; Berthus and Stanhouse (2001) analyze gold, more of an investible asset than a commodity. Moreover, our data covers a wide range of different commodities. Since most studies focus on a homogenous subset of commodities, only few studies have investigated a wider range of heterogeneous subset of commodities from agricultural to ferrous metals. [11]

Previously published studies on speculation in commodities markets used techniques that not only tested for the possible presence of bubbles, but also for the correct specification of the fundamental value relationships. Studies have used unit root tests (e.g., Brenner and Kroner, 1995; Barrett and Kolb, 1995; Bryant and Haigh, 2004; Brorsen, 1989; Castelino and Francis, 1982), and co-integration analysis (e.g., Chowdhury, 1991; Krehbiel and Adkins, 1993; Ma and Soenen, 1988; Ma, 1985; Heaney, 2002; Franses and Kofman, 1991; Kocagil, 1997; Chang, Chen and Chen, 1990), and the evidence on speculative behavior reported by these studies remains inconclusive, questioning the empirical validity of these techniques (c.f., Brenner and Kroner, 1995). The duration

[11] Examples of studies looking at a subset of commodities within the spectrum focus on industrial metals, grains, and livestock futures markets (for metals Franses and Kofman (1991); for livestock Schaefer, Myers and Koontz (2004). There are also studies that investigate one or possibly two closely related commodities (for energy commodities Emery and Qingfeng (2002)). Only very few papers investigate a range of commodities from agricultural to non-ferrous metals (e.g., Milonas (1986), Fraser and McKaig (2000), and in particular Chaudry and Christe-David, (1998)).

dependence test differs. *First*, it does not compare the time series behavior of the fundamental factors determining asset values with asset prices. *Second*, it does not require a correct identification of the underlying fundamental pricing model. These two features offer a distinct advantage over previously used bubble identification techniques by avoiding the joint testing of the null hypothesis of no presence of bubbles and no model misspecification. *Additionally*, the non-parametric technique provides a distinct advantage compared to the existing literature: it does not require normally distributed returns. Returns to both physical commodities and commodities futures exhibit both skewness and leptokurtosis (for a comprehensive overview, see Geman 2005). *Finally*, the method accommodates non-linearities in returns: non-linear returns are one of the characteristics of bubbles. Other studies testing for speculation in commodities markets using variance inequality tests (e.g., Wahab, 1995), or autocorrelation, skewness, and kurtosis of returns (e.g., Chaudry and Christie-David, 1998) assume linearity.

The results of the duration dependence test suggest some evidence of rational speculative bubbles in commodities: eleven of the twenty-eight commodities under investigation experienced some episodes of rational speculative bubbles. They are WTI, coffee, corn, soybean No.2, soybean meal, soybean oil, wheat No.2 soft red and wheat No. 2 hard winter, lean hogs, and gold and platinum in metals sector. Additionally, we report evidence of mean reversion in the interest-adjusted basis or excess returns in natural gas, propane, live cattle, and pork bellies. These results corroborate the findings of Antoshin and Samiei (2006) for crude oil and coffee, and confirm those of Berthus and Stanhouse (2001) regarding gold.

This study unfolds as follows. The following reviews briefly the literature on speculation in commodities and section III discusses the creation of the interest-adjusted basis and the testing methodology, duration dependence test. Section IV describes our data and section V summarizes our empirical results, with section VI concluding.

II. Previous studies

Previously published studies of speculative aspects of commodities markets focus mainly on the functions of speculators and the possible existence of simple profitable trading rules, temporary dislocations in the cost-of-carry implied arbitrage pricing relationship between the physical commodity and financial futures, and volatility migration across physical and financial commodity markets. These studies test, using their different methodologies, the behavior of commodities markets, (e.g., Working (1949); Brennan (1958); Telser (1958)).

One potential source of speculative profits is attributed to the liquidity effects of speculators. Relating liquidity costs with speculative returns in the corn futures market, Brorsen (1989) reported seasonality in speculative profits: during the critical summer growth period, trading in corn futures is relatively thin and speculative positions were rarely profitable. Closer to harvest, when both market liquidity and trading volume increased, speculative trading became more profitable. A subsequent study by Chatrath, Liang and Song (1997), assessed the magnitude of seasonal changes in the speculative profits in agricultural commodities. They concluded that speculative profits increased as risk premiums declined due to reduced need to hedge price exposure due to seasonal variations. The seasonality of speculative trading profits in agricultural commodities suggests a pattern reminiscent of speculative bubbles: prices are bid up in the anticipation of certain reversals. Not only agricultural commodities exhibit seasonal patterns in speculative profits, but also industrial commodities. For instance, Antoshin and Samiei (2006) focused on speculation in five commodities – crude oil, coffee, cotton, copper, and sugar. The results indicate that speculation in commodities is both cyclical and seasonal. Speculative pressures affect price levels in the long run and price swings in the short run. Speculation builds on price volatility, particularly short-term price swings. According to Antoshin and Samiei (2006) with hedgers entering the market, speculators follow and provide liquidity to the market. With increasing trading volumes, more trading strategies become profitable and speculative profits materialize.

Temporary dislocations in the cost-of-carry relation are usually modeled in a framework of cointegrated time series. A large number of studies use this approach to analyze speculative opportunities. For instance, Moosa and Al-Loughani (1995) looked at contemporaneous variation in the basis between physical crude oil, WTI, and financial crude oil futures by testing for the existence of cointegrating relationships between these price series. Booth et al (2001) analyze the relationship between Canadian and US wheat prices using cointegrating relationship and found that the series are closely related, allowing for hedging across these markets, reducing the opportunities for speculation.

Cai, Cheung and Wong (2001) explained speculative changes in the intraday volatility of gold using announcements of economic data on employment, gross domestic product, consumer price index, and personal income.[12] This example of volatility migration was also documented in Wahab (1995). Testing for the IID behavior of precious metal future prices following Lo and MacKinely's variance ratio test, the study reports that prices and price changes are not IID and the returns show significant serial correlations, indicating the existence of speculative forces in these commodities.

Speculative bubbles have only received limited attention. The sole published study explicitly examining the possible existence of speculative bubbles in commodities focuses on gold and gold futures. Berthus and Stanhouse (2001) analyze the market for gold. Both gold and gold futures exhibit characteristics more closely related to financial assets such as equities, than to commodities such as copper. Gold, as storage of value and safe haven under increased financial and political uncertainties, offer a natural conduit for testing the possible presence of speculative bubbles. Berthus and Stanhouse (2001) analyze the price determination process using a state-space model and then conduct a

[12] The study reports a U-shaped pattern for intraday volatility corresponding to opening and closing of trading sessions; volatility is high in the morning, declines during the middle of the trading session, to finally increase in the afternoon closer to the close. Additionally, the study finds an intraday pattern of non-linear returns and a persistence of changes in returns. Adranoi and Chatrath (2003) investigate the same phenomenon in agricultural commodities.

dynamic factor analysis using a Kalman filter[13]. Their estimates for the rational speculative bubble is significant at the 10% level.[14]

III. Methodology

We analyze the existence of potential rational speculative bubbles in commodities by focusing on the behavior of the interest-adjusted basis. To estimate the interest-adjusted basis, we need to approximate the convenience yield and match contiguous spot prices with unconnected futures prices.

Convenience yields and interest-adjusted basis

The theory of storage advanced by Working (1949), Brennan (1958) and Telser (1958) explains the futures price for a commodity, $F_{i,(T-t)}$, as a function of the spot price for the physical commodity, $S_{i,t}$, the interest foregone in storing the commodity, $R_{f,(T-t)}$, the warehousing costs, $W_{(T-t)}$, and the convenience yield from holding the commodity, $C_{(T-t)}$:

(1) $$\mathrm{F}_{\mathrm{i,tT}} = S_{i,t} e^{(Rf+W-C)(T-t)}$$

The convenience yield is a function of implicit and explicit benefits derived from having immediate access to the commodity held in inventory, and reflects the benefits stemming from possible alternative uses for the product as well as the ability to speculate in the

13 The study forecasts changes in the gold price based on the risk-free rate, S&P500 real returns, price indexes of Money Center Banks with international loan portfolio exposure, oil prices as a measure for economic uncertainty, producer prices to reflect economic production, and the CHF/USD exchange rate to reflect currency uncertainties.

14 The study reports speculative moments in the gold market during the 1973 OPEC initiated oil crises, the 1975 economic crisis, the 1980 silver crisis caused by spillovers from the Hunt brothers’ cornering both the spot and the futures markets for silver; the 1981-1983 effects of the third world debt crisis, the 1990 effects of the first Iraqi war in the early 1990s; and the 1991 effects of the uncertainties associated with the German reunification.

price appreciation of the underlying asset or the futures associated with the asset (c.f., Chatrath, Liang, and Song, 1997; and Considine and Larson, 2001). Routledge, Seppi, and Spatt (2000) have shown that convenience yields arise endogenously, and reflect the interaction among supply, demand, and storage decisions.[15]

To preclude arbitrage between the physical commodity and the financial futures, this cost-of-carry model requires that, the return from a long position in the futures between *t* and the maturity date of a corresponding future contract at *T*,, should provide the same return to the trader as a long position in the physical commodity adjusted for the interest foregone between *t* and *T* and the warehousing costs, reduced by the convenience yield. Taking logs of (1) and rearranging, yields the cost-of-carry relationship:

(2) $$\mathrm{f}_{\mathrm{i,tT}} - s_{i,t} = r_{f,tT} + w_{tT} - c_{tT}$$

Warehousing costs are time-invariant and relatively stable proportion of the physical commodity's value. Warehousing costs clearly diverge across commodities and even within the same commodity due to geographical, cost structure and accessibility factors. , Even in studies, where warehousing costs are theoretically relevant, (e.g., studies focusing on the relationship between inventory levels, and changes in inventory levels to predict pricing properties of the physical commodity), do not explicitly consider the influence warehousing has on the relationship between the physical commodity and futures prices. Brenner and Kroner (1995) argued that warehousing costs are irrelevant in the pricing relationship and are determined solely by stochastic property of the

[15] Convenience yield is presumed to be mean reverting and stationary due to equilibrium of the inventory and the mean reversion and stationarity property of inventory levels, Ng and Pirrong (1996).

convenience yield. [16] Our study, as most empirical studies do, disregards the cost of warehousing.

Thus, the relationship between the spot price of the physical commodity and associated financial futures in a non-arbitrage equilibrium is a function of the convenience yield and the risk-free rate of interest. In equilibrium, there are no opportunities to earn arbitrage profits. However, as empirical results indicate that speculative profits in the commodities markets do exist. Profitable speculation presumes the existence of series of temporary disequilibria, between the physical commodity price and the financial futures price, offering the opportunity to earn excess returns.[17] Adjusting the basis for the influence of this disequilibrium and rearranging yields the interest-adjusted basis:

(3) $$\mathrm{IAB}_{\mathrm{i,tT}} = \mathrm{f}_{\mathrm{i,tT}} - s_{i,t} - r_{f,tT} - c_{tT}$$

This interest-adjusted basis captures the possible excess returns from trading in both the physical and financial commodity markets, reflects the shape of the futures price curve, and can be either positive or negative. In contango, the interest-adjusted basis is negative. Intuitively, interest-adjusted basis corresponds to an excess return.Similar approach has been followed in both Mazaheri (1999), and Milonas and Henker (2001).

[16] Stationary variables can be omitted from a cointegrating regression without affecting the consistency of the coefficient estimates or the power of the accompanying hypothesis testing procedures. Thus, the net carrying costs and the mark-to-market adjustments can be omitted without influencing the findings, Sequeira and McAleer (2000). Differing evidence comes from Brenner and Kroner (1995), where the results indicate that while currency markets are cointegrated, commodity markets are not. These findings support some of the voiced difficulties in appropriately estimating the cost-of-carry relationships, Heaney (1998).

[17] Both in Ludkovski and Carmona (2004) and Casassus and Collin-Dufresne (2005) uses similar arguments for the interpretation of the interest-adjusted basis.

Creating contiguous prices series for futures

Physical commodity spot prices are contiguous, while financial futures prices are not and are limited by the lifetime of each futures contract. To match physical spot and financial futures price series, we would need a contiguous futures price series. Research offers two alternative strategies to create contiguous price series for futures: splicing the nearby futures prices into one[18] or weighting all futures prices by their time to maturity. Most studies choose the first alternative, a choice that introduces multiple biases.

First, the calculated value of each observation in the contiguous time series, depends on the effects the continuously narrowing of the time to maturity window have on the traded futures and the physical commodity prices. Such approach puts a considerable weight on the value of the nearest of the several existing futures contracts, even though nearby futures contracts may not be as relevant from a hedging perspective as distant futures contracts could be. Second, splicing of time-series assumes a continuous roll of the nearest futures contract around expiration, which in practice has skewing effects on prices. In practice, the liquidity of the market would determine both the price and volume effects of continuously rolling nearby futures contracts; liquidity effects on volume and execution are difficult to control and assess. Third, apart from the price bias introduced by splicing, it also introduces expiry related seasonality in addition to trends already existing in the data. These effects may be particularly pronounced in commodities that have quarterly expirations, and become particularly pronounced during increased seasonal demands for hedging, Simon (2002). Fourth, the differences in the conditional

[18] Milonas, 1986; Ng and Pirrong, 1994; Ng, Pirrong, and Craig, 1994; Walls, 1999; and Heaney, 2002

variance of the individual futures time series actually misestimate the unconditional variance of the spliced series, Fama and French (1988) and Sequeira and McAleer (2000).

Time to maturity weighting of all existing and traded futures contracts avoids some of these biases. Rougier (1996) proposes a time-invariant convex combination of all existing and traded contracts to create an optimal contiguous futures price series, *F**. The time-invariant combination reduces the effects of the continuously narrowing time-to-maturity and the direct effects of the roll, and does not introduce additional seasonality effects. This series is a function of each existing and traded contract[19]:

(4) $$F^* = \sum_{i=0}^{n-1} \lambda_i(t) F_{k+iv}$$

The time between contract maturities is *v*, and the individual contract specific time weights, λ_i, satisfy the dual necessary conditions of $\sum_{i=0}^{n-1} \lambda_i(t) = 1$ and $0 \leq \lambda_i(t) \leq 1$ for all values of *i* and *t*. To find the optimal index for *n* exiting and traded commodities futures contracts, the weights must satisfy these dual necessary conditions as well as the following two conditions:

(5) $$\sum_{i=0}^{n-1} \lambda_i'(t) = 0 \text{ and}$$

(6) $$v \sum_{i=0}^{n-1} i \lambda_i'(t) = 1,$$

19 Several studies follow the Rougier (1996) approach to create contiguous series of futures prices. These studies include Holmes and Tomsett (2004), an analysis of noise traders in UK futures markets, and Lien and Tse (1998), an analysis of the influence of the downside risk on hedging of commodities.

where $\lambda_i'(t)$ is the first derivative of $\lambda_i(t)$. In the *n = 2* or two contract case there is only one optimal time weighting of the components of the price index; for two futures contracts the optimal contiguous time series equals $F^* = \frac{k-t}{v}F_k + \frac{v-(k-t)}{v}F_{k+v}$, where F_k is the price of the nearest contract, F_{k+v} is the price of the next nearest contract, *v* is the time between expiry of the two adjacent contracts, and *k-t* represents the time to expiry. Since most commodities have multiple existing and traded contracts, in the *n = 2* or multiple contract case, there exist several potential optimal combinations of time weights in creating the *F** series. Aware of this feature of the Rougier (1996) approach, we selected that set of weights which yield a notional time, *v*, closest to the mean time to expiry of all existing and traded contracts in the market, because this approach mirrors the available trading opportunities to the participants in the futures markets.

Approximating the convenience yield

The convenience yield is not observable. Heaney (2002) develops and tests a method for estimating the convenience yield for commodities based on a stochastic non-arbitrage model for infrequently traded asset proposed in Longstaff (1985).[20] This method assumes that convenience yields are endogenously determined and stochastic.

The model assumes a trader has an initial long position in the physical commodity, perfect foresight and a time horizon for the trading strategy set at the maturity date of the

[20] Both Gibson and Schwartz (1990) and Schwartz (1997) develop stochastic convenience yield models. The practical benefit of these stochastic convenience yield models lies in developing term structures of commodities future prices. They do not, however, describe the endogenous factors determining the convenience yield.

financial futures, *T*. The trader assumes the storage expenses until the commodity price reaches its maximum level between *t* and *T*, when the trader, who has perfect foresight, sells the physical commodity at the maximum possible price or

$$(7) \qquad \mathrm{M}_{\mathrm{i,tT}} = \max\left\{\mathrm{S}_{\mathrm{it}}\mathrm{e}^{\mathrm{R}_{,\mathrm{ftT}}}\right\} \qquad \max 0 <= t <= T$$

Selling at the maximum possible price ensures both profit maximization and maximum possible convenience yield. The profit to the trader from this trading strategy, $TS(S_{i,tT})$ can be approximated by the value of an American option to sell the physical asset when its price rises sufficiently between *t* and *T*, to generate a profit for buying the physical asset back at the maturity of the futures contract at *T*:

$$(8) \qquad \mathrm{TS}\left(\mathrm{S}_{\mathrm{i,tT}}\right) = E\left[M_{i,tT}\right]e^{-R_{f,tT}} - E\left[S_{i,tT}\right]e^{-R_{f,tT}} = \left(E\left[M_{i,tT}\right] - E\left[S_{i,tT}\right]\right)e^{-R_{f,tT}} .$$

Assuming a Wiener process in both of the relevant price processes - the physical commodity and the financial futures - the profit from this trading strategy, under continuous compounding is:

$$(9) \qquad \mathrm{ts}\left(\mathrm{s}_{\mathrm{i,tT}}\right) = \left(\left(2 + \frac{\sigma_{i,tT}{}^{2}}{2}\right)N\left(\sqrt{\frac{\sigma_{i,tT}{}^{2}}{2}}\right) + \sqrt{\frac{\sigma_{i,tT}{}^{2}}{2\pi}e^{-\left(\frac{\sigma_{i,tT}{}^{2}}{8}\right)}}\right).$$

$N(*)$ is the cumulative normal distribution.

This trading strategy is available both to a trader with a long position in the commodity and a trader with a long position in the financial futures. This allows for a generalization to reflect the opposing initial position of the trade. When prices drop, the strategy is profitable if the physical commodity or the financial future is acquired at the lowest price between *t* and *T*, and then sold at a higher price at *T*. highest price Consequently, the convenience yield is the profit differential from initiating this trading strategy with a long position in the physical commodity or the futures, vs. a short position in the physical commodity or the futures:

(90) $$c_{i,tT} = ts_{i,t}\left(s_{i,tT}\right) - ts_{i,t}\left(f^{*}{}_{i,tT}\right).$$

This approximation of the convenience yield requires only two inputs: the time to maturity of the futures contracts and variance of the two price series. Using this approach offers a distinct modeling advantage over other approaches that attempt to incorporate the effects of reduced marketability due to the daily mark-to-market and the possibly incorrect pricing of the contract in relation to the underlying due to maturity, storage and convenience effects, (c.f. Brenner and Kroner, 1995; Milonas and Hencker, 2001; Ludkovski and Carmona 2004; and Casassus and Collin-Dufresne, 2005). Substituting (9) into (3), we estimate the interest-adjusted basis for all the 28 commodities in the study:

(11) $$\mathrm{IAB}_{\mathrm{i,tT}} = \mathrm{f}_{\mathrm{i,tT}} - s_{i,t} - r_{f,tT} - c_{i,tT} = \mathrm{f}_{\mathrm{i,tT}} - s_{i,t} - r_{f,tT} - \left\{ts_{i,t}\left(s_{i,tT}\right) - ts_{i,t}\left(f_{i,tT}\right)\right\}.$$

3.4 Duration dependence test

Based on these interest-adjusted basis series for each commodity in equation (11), the duration dependence test is performed. As noted earlier, the benefit of the duration dependence test does not require correct identification of the observable fundamental components. The focus is on the hazard rate (h_i) for runs of positive and negative returns. The hazard rate is defined as the probability of obtaining a negative abnormal (excess) return given a sequence of *i* prior positive abnormal (excess) returns, or $h_i = \mathrm{Prob}(\varepsilon_t < 0 \mid \varepsilon_{t-1} > 0, \varepsilon_{t-2} > 0 \ldots\ldots, \varepsilon_{t-i} > 0, \varepsilon_{t-i-1} < 0)$. Specifically, if a bubble exists, the hazard rates for runs of positive return decreases with i, $h_{i+1} < h_i$ for all i.[21] This condition, however, does not hold for runs of negative abnormal returns because rational expectations bubbles cannot be negative.

To apply the duration dependence test, the interest-adjusted basis of each commodity is transformed into run lengths of positive and negative returns. The numbers of runs of positive or negative excess returns of particular length i are then counted. The optimal hazard rate for length i is computed as $\hat{h}_i = N_i /(M_i + N_i)$, which is derived from maximizing the log-likelihood function of the hazard function in (13) with respect to h_i:

$$(12) \quad L(\theta \mid S_T) = \sum_{i=1}^{\alpha} N_i \text{ Ln } h_i + M_i \text{ Ln}(1-h_i) + Q_i \text{ Ln}(1-h_i),$$

where N_i is the number of completed runs of length i in the sample, and M_i and Q_i are the numbers of completed and partial runs with length greater than i, respectively. To test the null hypothesis, the functional form of the hazard function is defined as:

$$(13) \quad h_i = \frac{1}{1+e^{-(\alpha+\beta Lni)}}.$$

The duration dependence is performed by substituting equation (14) into (13) and maximizing the log likelihood function with respect to α and β. We use a logit regression to estimate the parameters of hazard function where the independent variable is the log of current run length and the dependent variable is 1 if the run ends in the next period and 0 if it does not. The null hypothesis of no rational expectations bubble implies that the probability of a positive run's ending is unrelated to prior returns. In other words, the hazard rate should be constant, or H_0: $\beta = 0$. The alternative hypothesis of a bubble

[21] For full derivation of this equation, see McQueen and Thorley (1994).

suggests that the probability of a positive run's ending should decrease with the length of the run, i.e., decreasing hazard rate, or H_1: $\beta < 0$. Under the null hypothesis of no bubble, the likelihood ratio test (LRT) is distributed asymptotically as χ^2 with one degree of freedom.

(14) $\quad LRT = 2[L_{UR} - L_R] \sim \chi^2_1$.

L_{UR} is the log-likelihood function using the maximum likelihood estimate (MLE) of the unrestricted parameters and L_R is the log-likelihood function using the MLE of the restricted parameters.

IV. Data [22]

Our study considers all 28 commodities with both spot price information on the physical commodity and information on the financial futures prices that are available from the Commodity Research Bureau (CRB database). The commodities cover the following five different commodity groups: [23]

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[22] Aware of multiple markets with spot price information on traded commodities, we defer to the spot price information provided by CRB data services for the spot prices. Fraser and McKaig (2000) offers an in-depth critical analysis on the validity of using spot prices in commodities markets and offers an alternative approach of imputing commodity spot prices from observable futures price series. The rationale behind this approach is that while there is usually one commodities futures market for a specific commodity in the United States, there are multiple spot markets for the underlying commodities. Consequently, reported commodity spot prices either reflect the observed pricing within one particularly market or average observed prices across these markets. While imputing commodity spot prices from observable futures price series counters the problems of averaging diverging commodity spot prices across markets, it uses time to maturity dependent price series, which magnifies expiry related seasonality.

[23] The symbols for the six commodities in the energy sector following the above order are CB, CL, HU, HO, NG, and PN, for the four commodities in the foodstuffs sectors are 02, KC, CT, and SB, for the nine commodities in grains and oilseeds sectors are WA, C-, WF, S-, SM, BO, W-, WW, and KW, for the four commodities in the livestock and meats

- energy sector: Brent crude oil, WTI crude oil, gasoline, heating oil, natural gas, and propane
- foodstuffs and industrial sector: butter, coffee, cotton, and sugar
- grains and oilseeds sector: barley, corn, flaxseed, soybean/No. 2, soybean meal, soybean oil, wheat/No. 2 soft red, wheat domestic feed, and wheat/No. 2 hard winter
- livestock and meats sector: cattle feeder, cattle live, lean hogs, and pork bellies
- five in metals sector: copper, gold, palladium, platinum, and silver

After collecting end-of-month prices for the physical commodity and all existing and traded financial future contracts associated with each commodity, we create *F** contiguous financial future price series . These series together with the end-of-month spot price for the commodity, the prevailing 13 week T-bill yield from the FRED database, yield the monthly cost-of-carry for each commodity. We approximated the convenience yield using the variance of the monthly prices for the preceding 12 months.[24]

Table 1 reports the detailed descriptive statistics on the monthly excess returns or interest-adjusted basis series for the 28 commodities. For 12 of the 28 commodities, the interest-adjusted basis is positive. Three in the energy sector - Brent crude oil, unleaded gasoline, and natural gas; three in the foodstuffs sector - butter, cotton, and sugar; four in the grains and oilseeds sector; barley, soybean No. 2, wheat No. 2 soft red, and domestic

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sector are FC, LC, LH, and PB, and for the five commodities in metals sector are HG, GC, PA, PL, and SI.

24 For some of these calculations, we used the freely available console version of Ox, Doornik (2006).

wheat; and two in the livestock and meats sector - lean hogs and pork bellies. All the five commodities in the metals sector exhibit negative interest-adjusted basis.

INSERT TABLE 1 AROUND HERE

The highest monthly interest-adjusted basis is that of hogs, 31.91% and the lowest is of high-grade copper, -16.97%. While this is a sizeable variation of the interest-adjusted basis, it is noteworthy that in most cases, the monthly interest-adjusted basis is between 1% and -1%. Our interest-adjusted basis estimates are comparable to those derived by Heaney (2002). The volatility of the monthly interest-adjusted basis ranges for the high of 64.31% for unleaded gasoline and the low of 1.09% for gold. Apart from the high volatility of copper, commodities in metals sector show low overall volatility as do the grains and oilseeds sector. On average, the highest volatility sector is the energy sector.

The third and fourth moments describing the distribution of monthly interest-adjusted basis offer some indication of the possible presence of rational speculative bubbles. Overall, these statistics shows significant skewness and excess kurtosis, with the exception of barley, soybean oil, wheat No.2, domestic wheat, cattle feeder, cattle live, and butter.

INSERT TABLE 2 AROUND HERE

The rational bubble model implies positive autocorrelation in returns while the bubble grows. Table 2 provides the autocorrelation coefficients and Ljung-Box Q-statistics for 6 and 12 lagged autocorrelation, Q(6) and Q(12), for each commodity. The autocorrelation coefficients are positive for lags 1 to 4, 6, and 12 for the Brent crude, coffee, sugar, soybean No. 2, soybean meal, soybean oil, wheat hard winter, cattle feeder, and copper. The Ljung-Box Q statistics strongly reject the null hypothesis of no autocorrelation up to lags 6 and 12 at the traditional significance level for all commodities, with the exception of some energy commodities, such as Brent crude, WTI, heating oil, propane, platinum, and unleaded gasoline up to lags 12. The persistence of positive autocorrelation for up to 6 and 12 months in the interest-adjusted basis series strengthens the possibility that bubbles could exist in commodities, but not necessarily in all energy commodities. These results need to be interpreted with some caution, however, as other factors could contribute to the excess return series. For instance, extensive empirical evidence suggests that both skewness and kurtosis reflect changing economic or political fundamentals rather than the emergence of speculative bubbles. Similarly, the seasonality of commodities could affect the autocorrelation pattern of these commodities. Moreover, asymmetric fundamentals and information asymmetry affecting publicly available news could cause skewness in returns andbatched arrival of information could cause leptokurtosis. Moreover, positive autocorrelation could result from time-varying and deterministic risk premium (e.g., Fama and French, 1988), emergence and evaporation of fads (e.g., Porterba and Summers, 1988), non-synchronous trading (e.g., Lo and MacKinlay, 1990), or pure psychological effects (e.g. Westerhoff, 2003).

V. Empirical results

Tables 3 to 7 provide the results of the duration dependence tests for rational speculative bubble on positive runs of the interest-adjusted basis classified in five groups: energy, foodstuffs and industrials, grains and oilseeds, livestock and meats, and metals.

Energy

Among the commodities in the *energy* sector, propane shows the highest total number of positive runs, 49 followed by 48 runs of unleaded gasoline, while Brent crude oil has the lowest number of positive runs, 27.[25] Heating oil has the longest run of 11 months, while propane shows two short positive runs of 5 months. It is likely that the positive runs in propane reflect recurring seasonal effects.

INSERT TABLE 3 AROUND HERE

As noted earlier, one characteristic of a rational expectations bubble is that the hazard rate should be a declining function of the length of positive runs; otherwise, a bubble cannot be sustained. The sample hazard rate can be used to determine the probability that a specific positive run ends after a particular run length *i* (bubble bursts), given that the run has lasted until *i* (bubble grows). For illustrative purposes, we focus on the Brent crude oil and compare it with WTI crude oil. For Brent crude oil, the hazard rate associated with positive run length of 4 months is 0.308. Moreover, there are exactly 4 runs that last 4 months, and there are 13 runs that last at least 4 months. These values

[25] The total numbers of positive runs for each commodity vary due to the use of different time periods.

determine the hazard rate, or 4/13 = 0.308. The hazard rate states that if a positive run persists for 4 consecutive months, there is a 30.80% probability that the bubble will burst in the next month. For WT I crude oil, the hazard rate associated with a run length of 4 is 0.25 (1/4). This indicates that there is a 25.00% probability that positive run lasting for 4 months will revert to a negative return in the next period. Runs of four are more likely to terminate after four months with Brent crude oil. The disparity in hazard rate between two similar commodities reflect possible variation in the market for these products, including differences in the cost-of-carry and convenience yield as well as qualitative differences.[26] The hazard rate of other commodities can be interpreted in the same way.

The duration dependence test focuses on the hazard rate estimate. The null hypothesis of no rational bubble implies a constant hazard rate (H_0: β=0). The alternative bubble hypothesis implies a negative sloping hazard function (H_a: β<0) for runs of positive excess returns. From Table 3, the logit regression estimates of β for all commodities are positive, with the exception of WTI crude oil, where the significant negative β coefficient of -1.0252 is consistent with a rational speculative bubble. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence, or constant hazard rate, is rejected at the 5% significance level with the LRT = 6.0872. Clearly, WTI has experienced speculative bubbles.

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[26] Brent oil is a light crude oil, extracted in the North Sea and WTI is sourced in Texas. Both Brent and WTI 0. are classified as sweet crude. WTI due to its lower sulfur content is considered to be sweeter than Brent. Brent is ideal for production of gasoline, and is typically refined in Northwest Europe, but when the market prices are favorable for export, it can be refined also in East or Gulf Coast of the United States. Historically, the typical price difference between Brent and WTI was $1 per barrel in the spot markets, a difference attributed to Brent's qualitative advantage. In recent years, the pricing relationship has switched to WTI's advantage, which is attributed to more localized factors in the US domestic crude and distillates markets.

For Brent crude oil, unleaded gasoline, heating oil #2, natural gas, and propane, the estimates of β are positive; β estimates of natural gas and propane are significant at the 5% level. The null hypothesis of $\beta=0$ is rejected in favor of $\beta>0$ with the LRT = 5.7768 at the 5% significance level for natural gas and LRT = 3.6161 at the 10% significance level for propane. A significant positive β is not consistent with the existence of a bubble; rather it implies that the excess return series of natural gas and propane exhibit a mean-reversion. In this mean-reversion process, the likelihood of positive excess return reverting to negative return in the next period increases as the established length of positive excess return increases.

Our empirical evidence on the behavior of the interest-adjusted basis for Brent Crude and WTI suggest the existence of a rational speculative bubble in the WTI, but not in the Brent Crude. For two commodities as closely linked as Brent Crude and WTI are, this finding is surprising and counters previously reported empirical evidence, e.g., Antoniu and Foster (1992); and Milonas and Henker (2001). We attribute our findings to the length of time-series we have used for the study. We use all available price information accessible on the CRB database, where price information on Brent futures starts in 1991 and covers 14 years, while the price information on WTI starts in 1985 and covers 20 years. A potential explanation is different volatility characteristics: our estimate of the interest-adjusted basis' volatility for the WTI is 2.8719 and for Brent 9.5180.

Food

In the *food* sector - butter, coffee, cotton, and sugar - cotton exhibits the longest positive excess return lasting for 52 months, and sugar exhibits three runs of the shortest positive excess return lasting for 9 months. Sugar has the highest total number of runs of positive excess returns, 92 and butter has the least number of positive runs, 16. The logit regression estimates of β for all four commodities are negative, but are not significant except for coffee. The null hypothesis of no bubble $\beta=0$ is rejected in favor of $\beta= -0.6364$ for coffee at the 5% significance level with the LRT = 5.0536. Therefore, out of the four commodities in food sector, rational speculative bubble only existed in coffee sometime between April 1974 and April 2005.

We attribute the presence of rational speculative bubbles in the coffee market to changes in the international coffee market. During the period of our study, the market has undergone significant changes with the collapse of the International Coffee Agreement in 1989, an agreement that kept global coffee prices artificially low between 1975 and 1989. After 1989, coffee prices as well as coffee price volatilities increased, and the higher prices prompted new entrants into the global markets, such as Vietnam, while other producers, such as Brazil, increased their exports of coffee, Love (1999). By 1998, coffee prices started a gradual decline due to global overproduction of coffee. Most of the new entrants into the international coffee markets produce Robusta coffee, which has a higher yield and lower production cost than Arabica coffee, Adrangi and Chatrath (2002). Both the spot coffee price and the NYBOT/ICE futures contract used to calculate the interest-adjusted basis is based on Robusta coffee, which is widely produced in Brazil, one of the largest coffee producers and exporters in the world.

INSERT TABLES 4 AND 5 AROUND HERE

Grains and oilseeds

Table 5 reports the duration dependence test results for nine commodities in the *grains and oilseed* sectors. Six commodities exhibit a characteristic that is consistent with a rational speculative bubble. The logit regression estimates of β are -0.4365 for corn, -0.4501 for soybean #2, -0.6640 for soybean meal, -0.9758 for soybean oil -0.2808 for wheat #2 soft red, and -0.7316 for wheat #2 hard winter, respectively. The null hypothesis of no bubble in these six commodities is rejected at the 5% level with the LRT= 4.9265 for corn; at the 1% level with LRT= 11.0115 for soybean #2, LRT =15.1864, for soybean meal, LRT=32.4804, for soybean oil, LRT =7.0593, and for wheat #2 hard winter; and at the 10% level with LRT= 3.3998 for wheat #2 soft red.

Overall, these findings suggest that rational speculative bubbles existed in corn between February 1961 and February 2005; for soybean #2 between March 1961 and May 2005; for soybean meal between April 1961 and May 2005; for soybean oil between March 1960 and April 2005; for wheat #2 soft red between April 1961 and April 2005, and for wheat #2 hard winter between April 1971 to April 2005. As the entire soybean spectrum – soybean #2, soybean meal, and soybean oil – exhibits rational speculative bubbles, confirms that in fact, there must have existed speculative pressures in this commodity. These pressures have impacted both soybeans and its derivatives: soybean meal and oil. Global production of soybeans has increased dramatically in the late 1980s with the entrance of Brazil as one of the largest exporter of soybeans. The United States remains one of the largest consumers of soybeans, particularly of soybean meal, which is used as animal feed; soybean meal is a direct competitor of corn for use as animal feed.[27] The existence of speculative bubble in the wheat spectrum – soft read and hard winter – may reflect seasonal patterns in the United States. The harvest period in the United States stretches from June to September. Only half of the wheat production can be stored, the rest is sold immediately. Consequently, there may be shorter periods of seasonal oversupply, particularly during the summer growing period. Since this seasonal price pattern is regular, speculative positions can be profitable, Dutt et al, (1997).

INSERT TABLE 6 AROUND HERE

Livestock and meats

Results in Table 6 show that the duration dependence test rejects the null hypothesis of no rational speculative bubble in lean hogs. For lean hogs, the β estimate is -0.6825, which is statistically significant at the 1% level; the log likelihood ratio test rejects the null hypothesis of no bubble in lean hogs at the 1% level with LRT = 12.93. Thus, lean hogs experience some episode of bubble during April 1968 to April 2005. On the other hand, both live cattle and pork bellies show positive and significant β estimates of 0.6479 and 0.3243, respectively. For cattle, the null hypothesis of $\beta=0$ is rejected in favor of $\beta>0$ at the 1% level and at the 10% level for pork bellies, which indicates that the excess

[27] We attribute the existence of speculative bubbles in corn to a spillover effects between two types of animal feed: soybean meal and corn. The corn traded on futures exchanges is feed corn, and not sweet corn used as food.

return series of these two commodities exhibit a mean reversion. The market for pork bellies exhibits high volatility, which is attributed to a relative large contingent of speculative traders in that market, Geman (2005).

INSERT TABLE 7 AROUND HERE

Metals

The duration dependence test results in Table 7 show evidence of rational speculative bubbles in two commodities in: gold and platinum. Except for palladium, the estimates of β of all commodities within this sector are negative. Only the β estimates of gold and platinum commodities are negative and statistically significant. The null hypothesis of $\beta=0$ is rejected in favor of $\beta= -1.2602$ at the 1% significance level for gold; for platinum the $\beta= -0.2515$ at the 10% significance level. These results indicate the existence of rational speculative bubbles in gold between April 1976 and February 2005 and in platinum between October 1986 and March 2005. These results are consistent with previously published studies regarding the behavior of gold prices, c.f., Berthus and Stanhouse (2001) and literature referenced therein.

VI. Conclusions

This study investigates the existence of rational speculative bubbles in commodities using the non-parametric duration dependence test developed by McQueen and Thorley (1994). Investigating speculation in commodities is a timely topic. Speculation in commodities, in particular the energy, ferrous metal and precious metal sectors, are believed to have contributed to a sizeable increase in the commodity prices according to recently published studies conducted by the OECD and the United States Senate.

We apply the duration dependence test on the monthly interest-adjusted basis, a measure of the potential excess returns earned on commodities Our empirical findings suggest that there is evidence of rational speculative bubbles in commodities: 11 of the 28 commodities in our study experienced episodes of rational speculative bubbles.

Rational speculative bubbles exist in WTI crude oil in the energy sector but not in Brent crude oil. We attribute the results to time differences in the available price information. In the foodstuffs and industrials sector coffee exhibits evidence for speculation, which we attribute to changes in the global market for coffee. The wide agricultural sector of commodities also shows evidence for speculative bubbles. In the grains and oilseeds sector, there is evidence of speculative bubbles in corn, soybean No.2, soybean meal, soybean oil, wheat No.2 soft red and wheat No. 2 hard winter. It is noteworthy that the entire soybean and a large part of the wheat sub-sectors have contained speculative bubbles. The existence of speculative bubbles in the wheat sub-sector is likely caused by seasonal price patterns: during the summer growing period, there is an expected oversupply of wheat, which usually disappears as wheat is harvested in the fall. In the livestock and meats sector lean hogs have contained speculative bubbles. Among ferrous metals gold and platinum show speculative bubbles; both these metals are considered as investible assets and not as industrial metals, e.g., Cai, et al., (2001) . Additionally, the duration dependence procedure also allows for the identification of mean reversion. For natural gas, propane, live cattle and pork bellies we report evidence of mean reversion.

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Table 1
Descriptive Statistics of Monthly Interest Adjusted Basis (IAB)

		Commodity	Future Exchange	Period	N	Mean	Std. Dev.	Skewness	Kurtosis
	Energy								
1	CB	Crude Oil, Brent/Global Spot	IPE	1991:02-2005:04	171	2.5939	9.5180	1.2952***	5.4614***
2	CL	Crude Oil WTI/Global Spot	NYMEX	1985:04-2005:05	242	-0.6179	2.8719	6.7024***	83.3574***
3	HU	Gasoline, Unleaded/Regular Non-Oxy	NYMEX	1986:02-2005:05	232	2.8581	64.3186	2.9790***	89.8816***
4	HO	Heating Oil#2/Fuel Oil	NYMEX	1980:01-2005:05	305	-0.8456	13.7762	-3.8758***	30.5078***
5	NG	Natural Gas, Henry Hub	NYMEX	1995:01-2005:07	127	0.9762	13.1534	-1.2933***	4.4119***
6	PN	Propane	NYMEX	1988:11-2005:05	199	-0.8456	13.7762	-3.8758***	30.5078***
	FoodStuffs and Industrials								
1	02	Butter, Aa	CME	1998:03-2005:04	86	0.4384	11.8742	-0.4784*	0.3271
2	KC	Coffee	NYBOT	1974:04-2005:04	373	-3.7353	6.5044	-2.2358***	9.8668***
3	CT	Cotton/1-1/16"	NYBOT	1980:04-2005:06	303	10.2821	20.3649	-2.8023***	40.7668***
4	SB	Sugar#11/World Raw	NYBOT	1962:03-2005:05	519	0.4965	16.7706	1.8328***	13.1018***
	Grains and Oilseeds								
1	WA	Barley, Western/No. 1	WCE	1993:04-2005:04	145	1.4501	8.2423	0.1136	6.9135***
2	C-	Corn/No. 2 Yellow	CBOT	1961:02-2005:02	529	-1.2371	4.5408	-1.1495***	6.9126***
3	WF	Flaxseed/No. 1	WCE	1993:04-2004:05	145	-1.2473	9.5194	-3.1402***	21.3280***
4	S-	Soybean/No. 2 Yellow	CBOT	1961:03-2005:05	531	1.0443	3.5106	-0.4690***	5.5396***
5	SM	Soybean Meal/48% Protein	CBOT	1961:04-2005:04	529	-1.9425	6.7891	-1.0174***	2.9250***
6	BO	Soybean Oil/Crude	CBOT	1960:03-2005:04	528	-1.3765	7.0806	0.2314	6.3701***
7	W-	Wheat/No. 2 Soft Red	CBOT	1961:04-2005:04	529	0.7650	7.0631	-0.1030	9.5778***
8	WW	WW Domestic Feed/No. 3	WCE	1993:04-2005:04	145	2.4577	10.5103	2.1327***	11.8064***
9	KW	Wheat/No. 2 Hard Winter	WCE	1971:04-2005:04	409	-3.8790	6.4383	-2.1764***	9.4340***
	Livestocks and Meats								
1	FC	Cattle, Feeder/Aveage	CME	1978:12-2005:02	315	-7.1285	6.2388	-0.1981	0.1971
2	LC	Cattle, Live/Choice Average	CME	1966:01-2005:05	473	-0.1075	7.6653	0.1678	3.6859***
3	LH	Hogs, Lean/Average Iowa/Smi	CME	1968:04-2005:04	445	31.9076	21.3809	0.6506***	2.7401***
4	PB	Pork Bellies, Frozen 12-14 lbs	CME	1964:05-2005:04	492	3.2964	10.0910	-0.5040***	3.4395***
	Metals								
1	HG	Copper/High Grade	NYMEX	1978:12-2005:02	315	-16.9722	25.3446	-1.0434***	2.1052***
2	GC	Gold	NYMEX	1976:04-2005:02	347	-0.4195	1.0934	0.3658***	26.9499***
3	PA	Palladium	NYMEX	1974:04-2005:04	202	-1.6485	4.9661	-9.2977***	108.6895***
4	PL	Platinum	NYMEX	1986:10-2005:03	222	-0.2406	1.8712	9.6208***	126.8995***
5	SI	Silver	NYMEX	1976:07-2005:05	443	-0.3943	1.6815	3.6029***	61.0970***

Notes: The spot and future prices of each commodity are obtained from Commodity Research Bureau (CRB). The future exchanges are International Petroleum Exchange (IPE), New York Mercantile Exchanges (NYME), Chicago Mercantile Exchange (CME), New York Board of Trade (NYBOT), Winnipeg Commodity Exchange (WCE), and Chicago Board of Trade (CBOT). The descriptive statistics are provided for the interest adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry are calculated as $F\text{-}S\ e^{(rf)*(t-T)}$. F denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. The study period for each commodity varies depending on the availability of the data. N is the number of quarterly observatons. Mean and standard deviations are expressed in percent. Asymptotic standard of skewness is $(6/N)^{1/2}$. Asymptotic standard errors of coefficient of excess kurtosis is $(24/N)^{1/2}$. ***, **, and * indicate significance at the 1%, 5%, and 10% level, respectively.

Table 2
Autocorrelation of Monthly Interest Adjusted Basis (IAB)

		Commodity	Autocorrelation						Ljung Box Statistics	
			ρ_1	ρ_2	ρ_3	ρ_4	ρ_6	ρ_{12}	Q (6)	Q(12)
	Energy									
1	CB	Crude Oil, Brent/Global Spot	0.4224	0.4522	0.2896	0.2441	0.2536	0.2320	112.4189***	178.0738***
2	CL	Crude Oil WTI/Global Spot	0.0763	0.0827	0.1576	-0.0082	0.1167	0.0016	13.5764**	16.6633
3	HU	Gasoline, Unleaded/Regular Non-Oxy	0.0146	-0.0366	0.2397	-0.0113	-0.0175	0.0019	14.1949**	15.5807
4	HO	Heating Oil#2/Fuel Oil	0.1117	-0.0562	0.0696	0.0589	-0.0667	0.0174	8.1006	14.6712
5	NG	Natural Gas, Henry Hub	0.2973	0.1539	0.0038	-0.0184	-0.0491	0.1918	15.0274**	29.1033***
6	PN	Propane	0.1117	-0.0562	0.0696	0.0589	-0.0667	0.0174	8.1006	14.6712
	FoodStuffs									
1	02	Butter, Aa	0.1885	0.1437	-0.0205	-0.1122	-0.1905	0.2845	12.9461**	36.2372***
2	KC	Coffee	0.4913	0.5560	0.4320	0.2377	0.2484	0.4081	359.9608***	553.1516***
3	SB	Sugar#11	0.1091	0.0329	0.1382	0.1318	0.0446	0.1532	28.5794***	57.6447***
4	CT	Cotton/1-1/16"	0.0861	0.1459	0.0209	-0.0807	-0.0954	0.3289	26.1385***	74.1705***
	Grains and Oilseeds									
1	WA	Barley, Western/No. 1	0.2900	0.1244	-0.1039	-0.1181	-0.0989	0.4353	20.1559***	64.3285***
2	C-	Corn/No. 2 Yellow	0.4718	0.3998	0.1880	0.1955	0.1693	0.4051	267.9995***	475.6181***
3	WF	Flaxseed/No. 1	0.1385	0.1710	0.0129	-0.1450	-0.0401	0.0167	16.6309***	65.7817***
4	S-	Soybean/No. 2 Yellow	0.3322	0.3271	0.1591	0.3076	0.2969	0.5108	241.8948***	541.1143***
5	SM	Soybean Meal/48% Protein	0.6393	0.5553	0.4257	0.4141	0.3326	0.4064	709.6470***	1069.0899***
6	BO	Soybean Oil/Crude	0.6438	0.7079	0.6071	0.5479	0.4379	0.3862	1117.2361***	1584.1487***
7	W-	Wheat/No. 2 Soft Red	0.4781	0.5136	0.4013	0.3038	0.2354	0.4706	470.5884***	784.5618***
8	WW	WW Domestic Feed/No. 3	0.3401	0.3393	0.0284	-0.0327	0.1314	0.4547	39.9205***	87.7485***
9	KW	Wheat/No. 2 Hard Winter	0.4593	0.5243	0.4386	0.2136	0.2195	0.4256	363.3654***	559.7293***
	Livestocks and Meats									
1	FC	Cattle, Feeder/Aveage	0.5519	0.2826	0.2200	0.2639	0.2371	0.6031	197.1716***	432.3922***
2	LC	Cattle, Live/Choice Average	0.2800	0.1021	-0.0331	-0.1451	0.0522	0.1782	54.3668***	87.5634***
3	LH	Hogs, Lean/Average Iowa/Smi	0.0427	0.6089	-0.0455	0.5266	0.5813	0.7306	446.4805***	928.8651***
4	PB	Pork Bellies, Frozen 12-14 lbs	0.3255	0.1765	0.0774	-0.0037	0.0332	0.5238	71.5739***	258.1218***
	Metals									
1	HG	Copper/High Grade	0.7264	0.6890	0.5797	0.6078	0.6136	0.5259	778.7388***	1215.9330***
2	GC	Gold	-0.0584	0.3058	0.0506	0.0901	0.0392	0.0336	48.6249***	67.9561***
3	PA	Palladium	0.2326	0.1742	0.0398	0.0067	0.0238	0.0645	18.0740***	23.6364**
4	PL	Platinum	0.0995	0.0638	0.0812	0.0703	0.0247	-0.0042	5.9107	12.2672
5	SI	Silver	0.0012	0.0680	0.1233	-0.1044	0.0507	0.0016	18.9280***	20.9786**

Notes: The spot and future prices of each commodity are obtained from Commodity Research Bureau (CRB). The autocorrelation coefficients for lags 1 to 4, 6 and 12 are provided for the interest adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry are calculated as $F\text{-}S\ e^{(rf)*(t-T)}$. F denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. The Ljung-Box (1978) portmanteau statistics Q(6) and Q(12) are the test statistics under the null hypothesis of no autocorrelation up to lag 6 and 12. They are distributed as χ^2 with 6 and 12 degrees of freedom. ***, **, and * indicate significance at the 10%, 5%, and 1% level, respectively.

Table 3
Duration Dependence Test for Rational Speculative Bubbles in Commodities in Energy Sector

	CB		CL		HU		HO		NG		PN	
Run Length	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate
1	5	0.1852	27	0.7500	20	0.4167	13	0.3250	3	0.1250	20	0.4082
2	8	0.3636	5	0.5556	8	0.2857	1	0.0370	7	0.3333	18	0.6207
3	1	0.0714	0	0.0000	6	0.3000	7	0.2692	3	0.2143	5	0.4545
4	4	0.3077	1	0.2500	5	0.3571	4	0.2105	3	0.2727	4	0.6667
5	3	0.3333	2	0.6667	6	0.6667	6	0.4000	2	0.2500	2	1.0000
6	0	0.0000	0	0.0000	2	0.6667	1	0.1111	5	0.8333	0	0.0000
7	2	0.3333	0	0.0000	1	1.0000	4	0.5000	0	0.0000	0	0.0000
8	0	0.0000	1	1.0000	0	0.0000	1	0.2500	1	1.0000	0	0.0000
9	2	0.5000	0	0.0000	0	0.0000	2	0.6667	0	0.0000	0	0.0000
10	2	1.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
11	0	0.0000	0	0.0000	0	0.0000	1	1.0000	0	0.0000	0	0.0000
Total Positive Run	27		36		48		40		24		49	
Log-Logistic Test												
α		-1.3071***		0.8579**		-0.5722**		-1.2468***		-1.8375***		-0.3312
β		0.2131		-1.0252**		0.1856		0.2085		0.9551**		0.7884**
LRT of H_0: $\beta = 0$		0.4773		6.0872**		0.3753		0.6367		5.7768**		3.6160*
(p-value)		(0.4896)		(0.0136)		(0.5401)		(0.4248)		(0.0162)		(0.0572)

Notes : The duration dependence test is performed on interest-adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry is calculated as $F\text{-}S\ e^{(rf)*(t-T)}$. *F* denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. CB denotes crude oil brent, CL denotes crude oil WTI, HU denotes unleaded gasoline, HO denotes heating oils #2, NG denotes natural gas, and PN denotes propane. Total positive runs do not include the runs which may occur at the beginning or at the end of period investigated. The sample hazard rate, $h_i = N_i/(M_i + N_i)$, indicates probability that a run ends at length *i* provided it lasts until *i* . β is the the hazard rate which is estimated using a logit regression where the independent variable is the log of current length of runs and dependent variable is 1 if a run ends and 0 if it does not end in the next period. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence or constant hazard rate (H_0: $\beta = 0$) is asymptotically distributed χ^2 with one degree of freedom. The critical values are 6.635, 3.841 and 2.706 at the 1%, 5%, 10% significance levels, respectively. P-value is the marginal significance level--the probability of obtaining the calculated value of LRT or higher under the null hypothesis. ***, **, and * Indicate significance at the 1%, 5%, and 10% level, respectively.

Table 4
Duration Dependence Test for Rational Speculative Bubbles in Commodities in Food Sector

	02		KC		SB		CT	
Run Length	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate
1	9	0.5625	10	0.4762	42	0.4565	3	0.1667
2	1	0.1429	2	0.1818	17	0.3400	0	0.0000
3	0	0.0000	2	0.2222	12	0.3636	2	0.1333
4	0	0.0000	2	0.2857	6	0.2857	0	0.0000
5	2	0.3333	0	0.0000	6	0.4000	1	0.0769
6	2	0.5000	0	0.0000	3	0.3333	1	0.0833
7	0	0.0000	0	0.0000	2	0.3333	1	0.0909
8	1	0.5000	1	0.2000	1	0.2500	1	0.1000
9	0	0.0000	2	0.5000	3	1.0000	0	0.0000
10	0	0.0000	0	0.0000	0	0.0000	0	0.0000
11	1	1.0000	0	0.0000	0	0.0000	1	0.1111
12……	0	0.0000	1	0.5000	0	0.0000	0	0.0000
17	0	0.0000	0	0.0000	0	0.0000	2	0.2500
18	0	0.0000	0	0.0000	0	0.0000	0	0.0000
19	0	0.0000	1	1.0000	0	0.0000	1	0.1667
20	0	0.0000	0	0.0000	0	0.0000	1	0.2000
21…….	0	0.0000	0	0.0000	0	0.0000	1	0.2500
32	0	0.0000	0	0.0000	0	0.0000	1	0.3333
33……..	0	0.0000	0	0.0000	0	0.0000	1	0.5000
52	0	0.0000	0	0.0000	0	0.0000	1	1.0000
Total Positive Runs	16		21		92		18	
Log-Logistic Test								
α		-0.2628		-0.3995		-0.2873		-2.3171***
β		-0.5942		-0.6364**		-0.1977		-0.1247
LRT of H_0: $\beta = 0$		2.2745		5.0536**		0.9878		0.2818
(p-value)		(0.1315)		(0.0245)		(0.3202)		(0.5955)

Notes : The duration dependence test is performed on interest-adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry is calculated as $F\text{-}S\, e^{(rf)*(t-T)}$. F denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. Total positive runs do not include the runs which may occur at the beginning or at the end of period investigated. The sample hazard rate, $h_i = N_i/(M_i + N_i)$, indicates probability that a run ends at length i provided it lasts until i . β is the the hazard rate which is estimated using a logit regression where the independent variable is the log of current length of runs and dependent variable is 1 if a run ends and 0 if it does not end in the next period. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence or constant hazard rate (H_0: $\beta = 0$) is asymptotically distributed χ^2 with one degree of freedom. The critical values are 6.635, 3.841 and 2.706 at the 1%, 5%, and 10% significance levels, respectively. P-value is the marginal significance level--the probability of obtaining the calculated value of LRT or higher under the null hypothesis. ***, **, and * Indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 5
Duration Dependence Test for Rational Speculative Bubbles in Commodities of Grains and Oilseeds Sector

	WA		C-		WF		S-		SM		BO		W-		WW		KW	
Run Length	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate
1	6	0.375	24	0.4138	4	0.2667	12	0.2308	18	0.4186	22	0.5366	12	0.2353	5	0.2632	12	0.5217
2	0	0.000	12	0.3529	1	0.0909	10	0.2500	3	0.1200	7	0.3684	7	0.1795	2	0.1429	2	0.1818
3	0	0.000	9	0.4091	1	0.1000	5	0.1667	9	0.4091	2	0.1667	7	0.2188	3	0.2500	2	0.2222
4	1	0.100	2	0.1538	5	0.5556	5	0.2000	1	0.0769	2	0.2000	4	0.1600	2	0.2222	2	0.2857
5	1	0.111	1	0.0909	0	0.0000	1	0.0500	2	0.1667	1	0.1250	4	0.1905	0	0.0000	0	0.0000
6	0	0.000	2	0.2000	1	0.2500	1	0.0526	3	0.3000	0	0.0000	3	0.1765	2	0.2857	0	0.0000
7	1	0.125	2	0.2500	1	0.3333	0	0.0000	0	0.0000	0	0.0000	4	0.2857	2	0.4000	0	0.0000
8	3	0.429	1	0.1667	1	0.5000	2	0.1111	0	0.0000	1	0.1429	2	0.2000	0	0.0000	1	0.2000
9	2	0.500	2	0.4000	1	1.0000	4	0.2500	0	0.0000	0	0.0000	0	0.0000	0	0.0000	2	0.5000
10	1	0.500	2	0.6667	0	0.0000	6	0.5000	1	0.1429	0	0.0000	4	0.5000	1	0.3333	0	0.0000
11	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.5000	0	0.0000
12	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.5000
13	0	0.000	0	0.0000	0	0.0000	1	0.1667	0	0.0000	1	0.1667	0	0.0000	0	0.0000	0	0.0000
14	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.2000	0	0.0000	0	0.0000	0	0.0000
15	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
16	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.2500	0	0.0000	0	0.0000
17	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.2500	1	0.3333	0	0.0000	0	0.0000
18	0	0.000	0	0.0000	0	0.0000	0	0.0000	1	0.1667	1	0.3333	0	0.0000	0	0.0000	0	0.0000
19	0	0.000	1	1.0000	0	0.0000	0	0.0000	4	0.8000	0	0.0000	0	0.0000	1	1.0000	1	1.0000
20	0	0.000	0	0.0000	0	0.0000	1	0.2000	0	0.0000	0	0.0000	1	0.5000	0	0.0000	0	0.0000
21	1	1.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	0.5000	0	0.0000	0	0.0000	0	0.0000
22	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
23…….	0	0.000	0	0.0000	0	0.0000	1	0.2500	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
29	0	0.000	0	0.0000	0	0.0000	0	0.0000	1	1.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
30	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
31…….	0	0.000	0	0.0000	0	0.0000	1	0.3333	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
41…….	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	1.0000	0	0.0000	0	0.0000	0	0.0000
45	0	0.000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	1.0000	0	0.0000	0	0.0000
46	0	0.000	0	0.0000	0	0.0000	1	0.5000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
47	0	0.000	0	0.0000	0	0.0000	1	1.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
Total Positive Run	16		58		15		52		43		41		51		19		23	
Log-Logistic Test																		
α		-1.3563**		-0.3412		-1.3979***		-1.0866***		-0.5153**		-0.0037		-1.1248***		-1.3345***		-0.2314
β		-0.1752		-0.4365**		0.0634		-0.4501***		-0.6640***		-0.9758***		-0.2808*		-0.0511		-0.7316**
LRT of H_0: $\beta = 0$		0.3008		4.9265**		0.0343		11.0115***		15.1864***		32.4804***		3.3998*		0.0301		7.0593***
(p-value)		(0.5833)		(0.0264)		(0.8530)		(0.0009)		(0.0000)		(0.0000)		(0.0652)		(0.8622)		(0.0078)

Notes : The duration dependence test is performed on interest-adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry is calculated as F-S $e^{(rf)*(t-T)}$. *F* denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. WA denotes Barley, C- denotes Corn, WF denotes Flaxseed, S- denotes Soybean#2 Yellow, SM denotes Soybean Meal, BO denotes Soybean Oil, W- denotes Wheat#2 Soft Red, WW denotes Wheat Domestic Feed, and KW denotes Wheat#2 Hard Winter. Total positive runs do not include runs which may occur at the beginning or at the end of period investigated. The sample hazard rate, $h_i = N_i/(M_i + N_i)$, indicates probability that a run ends at length i provided it lasts until i. β is the the hazard rate which is estimated using a logit regression where the independent variable is the log of current length of runs and dependent variable is 1 if a run ends and 0 if it does not end in the next period. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence or constant hazard rate (H_0: $\beta = 0$) is asymptotically distributed χ^2 with one degree of freedom. The critical values are 6.635, 3.841 and 2.706 at the 1%, 5% and 10% significance levels, respectively. P-value is the marginal significance level--the probability of obtaining the calculated value of LRT or higher under the null hypothesis. ***, **, and * Indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 6
Duration Dependence Test for Rational Speculative Bubbles in Commodities in Livestocks Sector

	FC		LC		LH		PB	
Run Length	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate
1	10	0.5000	25	0.2976	1	0.1429	13	0.2000
2	5	0.5000	19	0.3220	0	0.0000	3	0.0577
3	2	0.4000	13	0.3250	0	0.0000	7	0.1429
4	1	0.3333	15	0.5556	0	0.0000	10	0.2381
5	1	0.5000	6	0.5000	1	0.1667	3	0.0938
6	1	1.0000	4	0.6667	0	0.0000	1	0.0345
7	0	0.0000	2	1.0000	1	0.2000	3	0.1071
8	0	0.0000	0	0.0000	1	0.2500	7	0.2800
9	0	0.0000	0	0.0000	2	0.6667	5	0.2778
10	0	0.0000	0	0.0000	0	0.0000	7	0.5385
11	0	0.0000	0	0.0000	1	1.0000	3	0.5000
12	0	0.0000	0	0.0000	0	0.0000	2	0.6667
16	0	0.0000	0	0.0000	0	0.0000	1	1.0000
Total Positive Run	20		84		7		65	
Log-Logistic Test								
α		-0.0359		-1.0119***		-1.5524***		-1.9436***
β		-0.0245		0.6479***		-0.6825***		0.3243*
LRT of H_0: $\beta = 0$		0.0020		7.6512***		12.9309***		3.1843*
(p-value)		(0.9640)		(0.0056)		(0.0003)		(0.0743)

Notes : The duration dependence test is performed on interest-adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry is calculated as $F\text{-}S\ e^{(rf)*(t-T)}$. *F* denotes the future price which is constructed as the continguous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. FC denotes Feeder Cattle, LC denotes Live Cattle, LH denotes Lean Hogs, and PB denotes Pork Bellies. Total positive runs do not include the runs which may occur at the beginning or at the end of period investigated. The sample hazard rate, $h_i = N_i/(M_i + N_i)$, indicates probability that a run ends at length *i* provided it lasts until i. β is the the hazard rate which is estimated using a logit regression where the independent variable is the log of current length of runs and dependent variable is 1 if a run ends and 0 if it does not end in the next period. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence or constant hazard rate (H_0: $\beta = 0$) is asymptotically distributed χ^2 with one degree of freedom. The critical values are 6.635, 3.841 and 2.706 at the 1%, 5% and 10% significance levels, respectively. P-value is the marginal significance level--the probability of obtaining the calculated value of LRT or higher under the null hypothesis. ***, **, and * Indicate significance at the 1%, 5%, and 10% levels, respectively.

Table 7
Duration Dependence Test for Rational Speculative Bubbles in Commodities in Metal Sector

	HG		GC		PA		PL		SI	
Run Length	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate	Actual Run Counts	Sample Hazard Rate
1	5	0.2778	37	0.8043	15	0.7500	22	0.6286	42	0.6000
2	3	0.2308	3	0.3333	5	1.0000	7	0.5385	14	0.5000
3	3	0.3000	3	0.5000	0	0.0000	4	0.6667	9	0.6429
4	1	0.1429	1	0.3333	0	0.0000	0	0.0000	1	0.2000
5	1	0.1667	1	0.5000	0	0.0000	1	0.5000	2	0.5000
6	1	0.2000	0	0.0000	0	0.0000	1	1.0000	1	0.5000
7	1	0.2500	1	1.0000	0	0.0000	0	0.0000	0	0.0000
8	0	0.0000	0	0.0000	0	0.0000	0	0.0000	1	1.0000
9	1	0.3333	0	0.0000	0	0.0000	0	0.0000	0	0.0000
10	1	0.5000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
11	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
12	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
13	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
14	0	0.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
15	1	1.0000	0	0.0000	0	0.0000	0	0.0000	0	0.0000
Total Positive Runs	18		46		20		35		70	
Log-Logistic Test										
α		-1.0339**		1.2551***		1.1630**		0.4912		0.3855*
β		-0.1221		-1.2602***		0.5055		-0.2515		-0.3202
LRT of H_0: $\beta = 0$		0.1379		7.4723***		2.4040		3.1843*		1.0118
(p-value)		(0.7104)		(0.0062)		(0.1210)		(0.0743)		(0.3144)

Notes: The duration dependence test is performed on interest-adjusted basis (IAB). IAB is the difference between costs of carry and convenience yield. Costs of carry is calculated as $F\text{-}S\ e^{(rf)*(t-T)}$. F denotes the future price which is constructed as the contingous price index that reflects a time weighted mean of the price of the nearest and next nearest contracts. HG denotes Copper, GC denotes Gold, PA denotes Palladium, PL denotes Platinum, and SI denotes Silver. Total positive runs do not include the runs which may occur at the beginning or at the end of period investigated. The sample hazard rate, $h_i = N_i/(M_i + N_i)$, indicates probability that a run ends at length i provided it lasts until i. β is the the hazard rate which is estimated using a logit regression where the independent variable is the log of current length of runs and dependent variable is 1 if a run ends and 0 if it does not end in the next period. The likelihood ratio test (LRT) of the null hypothesis of no duration dependence or constant hazard rate (H_0: $\beta = 0$) is asymptotically distributed χ^2 with one degree of freedom. The critical values are 6.635, 3.841 and 2.706 at the 1%, 5% and 10% significance levels, respectively. P-value is the marginal significance level--the probability of obtaining the calculated value of LRT or higher under the null hypothesis. ***, **, and * Indicate significance at the 1%, 5%, and 10% levels, respectively.