ESSAYS IN FINANCIAL ECONOMICS

RESEARCH IN FINANCE

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RESEARCH IN FINANCE VOLUME 35

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This volume is dedicated to Dr John William Kensinger, Professor of Finance at University of North Texas, USA, who served as Editor-in-Chief of *Research in Finance* since Volume 26 (2010) until his untimely passing in July 2017. A retired Colonel from the U.S. Air Force (USAF), he served in Thailand and Germany as an Imagery Intelligence Officer during the Vietnam War. He was released from active duty in 1975 but continued to serve in various capacities till 1999, when he retired from the USAF. He obtained his Bachelor of Arts from Miami University, Oxford, OH, USA, majoring in English, in 1968, followed by an MBA. from the University of Utah, during his service in Germany. He received his PhD in Finance from Ohio State University in 1983. A recipient of several teaching awards at various institutions including University of North Texas, he was a Prolific Researcher. His work has been published in *Journal of Financial Economics*, *Financial Management*, *Journal of Financial Services Research*, and *Managerial and Decision Economics*, to name a few. He was particularly recognized for his pioneering work on real options as early as in 1987.

CONTENTS

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INTRODUCTION

This volume starts with a study examining the NYMEX Crude oil market. It uses a no-arbitrage futures equilibrium cost-of-carry model that incorporates both the quality delivery option as well as the timing delivery option in the NYMEX contract. It finds support for the NYMEX futures price to be an unbiased estimator of the futures spot prices. Switching gears, this work is followed by two chapters focusing on the growth of firms, one for US firms and one for firms in India. Using a sample of S&P 500 firms, the first study finds that the impact of corporate financial decisions on the growth of a firm vary in the face of different degrees of asymmetric information; lower asymmetric information leads to favorable effects while higher asymmetric information leads to adverse effects of financial decisions on the growth of the firm. The other chapter on growth, utilizing a sample of firms from India's manufacturing sector, examines growth as a performance measure for firms. It finds that the growth option is not always beneficial; if a firm does not increase its asset base to pursue a growth option, it might end up with higher systematic risk. The fourth chapter continues with a country-specific study: it finds support for the Fama-French (FF) five-factor model for firms on the Paris Bourse with the additional finding that the investment risk premium (the fifth FF factor) is better priced in the French stock market than the profitability factor (the fourth factor). Continuing in a similar vein of a country-specific study, the next study examines the volatility of the Indian stock market using the Bombay Stock Exchange Limited Sensitivity Index (BSE Sensex). GARCH models detect the presence of clustering, time-varying volatility with positive correlations with daily stock returns. The next chapter is also a country-specific study in the Italian banking industry. It finds that the use of derivatives has a positive impact on the profitability of Italian banks including during the global financial crisis period and the Italian recession period and advocates for the continued use of derivatives in that sector. Finally, this volume closes with a chapter examining the relationship between the US Dollar Index and several emerging stock market indices using Granger causality tests; the results indicate that the US Dollar Index and selected emerging stock markets have a negative relationship, especially during the period following former Federal Reserve Bank Chairman Bernanke's "tapering" talk.

Rita Biswas
Series Editor
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MARKET EFFICIENCY, ARBITRAGE, AND DELIVERY OPTIONS IN THE NYMEX CRUDE OIL MARKET

Don N. MacDonald and Hirofumi Nishi

ABSTRACT

This chapter develops a no-arbitrage, futures equilibrium cost-of-carry model to demonstrate that the existence of cointegration between spot and futures prices in the New York Mercantile Exchange (NYMEX) crude oil market depends crucially on the time-series properties of the underlying model. In marked contrast to previous studies, the futures equilibrium model utilizes information contained in both the quality delivery option and convenience yield as a timing delivery option in the NYMEX contract. Econometric tests of the speculative efficiency hypothesis (also termed the "unbiasedness hypothesis") are developed and common tests of this hypothesis examined. The empirical results overwhelming support the hypotheses that the NYMEX future price is an unbiased predictor of future spot prices and that no-arbitrage opportunities are available. The results also demonstrate why common tests of the speculative efficiency hypothesis and simple arbitrage models often reject one or both of these hypotheses.

JEL classifications: G12, G13, G14, G17

Keywords: Market efficiency; arbitrage; crude oil pricing; energy futures; delivery options; cointegration

The issue of whether commodity markets are efficient has produced a voluminous literature. Empirical tests are based on the principle that futures prices reflect all publicly available information (Fama, 1970).[1] Under the joint assumptions of

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rational expectations and risk neutrality, the speculative efficiency or "unbiasedness" hypothesis is given by $F_{t-i} = E_{t-i}(S_t)$ and often involves a regression of the form[2]:

$$Ln(S_t) = \alpha + \beta Ln(F_{t-i}) + \mu_t \tag{1}$$

where $Ln(S_t)$ is the log spot price at time t, $Ln(F_{t-i})$ is the log futures price at time $t-i$ and $E(\mu_t, \mu_{t-i}) = 0$ for all $i \neq 0$. Traditional tests of the speculative efficiency hypothesis or equation (1) involve a joint test of the hypotheses that $\alpha = 0$, $\beta = 1$ and that the disturbance term is not serially correlated. Extensions of the analysis have examined the stochastic properties of the underlying variables as well as additional explanatory variables that are available in period $t-i$.[3]

An interesting and often overlooked aspect of the speculative efficiency hypothesis is that unbiased forecasting of the expected spot price using the current futures price is neither a necessary component of either rational expectations or an efficient market approach (Fama, 1991). For example, Bilson (1981) and Dwyer and Wallace (1992) demonstrate this by constructing examples of markets in which market expectations are rational, but in which futures prices are not equal to the future spot price due to transaction costs and risk aversion. Furthermore, they present the possibility of constructing a framework in which markets are efficient in the sense of removing any opportunity for riskless arbitrage or excess returns, but the futures price forecast is predicatively biased. In marked contrast to the speculative efficiency hypothesis, Dwyer and Wallace (1992) and Brenner and Kroner (1995) define market efficiency as a lack of arbitrage opportunities and demonstrate that no general equivalence between market efficiency and, more generally, cointegration exists.[4]

This chapter develops a no-arbitrage, futures equilibrium cost-of-carry model to show that the existence of cointegration between spot and futures prices in the New York Mercantile Exchange (NYMEX) crude oil market depends crucially on the time-series properties of the underlying cost-of-carry differential. To preview the analysis and importance of the stochastic properties of the cost of carry components, consider the following no-arbitrage equilibrium model often employed in previous studies (Brenner & Kroner, 1995)

$$Ln(S_t) - Ln(F_{t-k}) = \alpha - Ln(D_{t-k}) \tag{2}$$

where $Ln(S_t)$ and $Ln(F_{t-k})$ are as in equation (1) and D_{t-k} is the expected net cost-of-carry differential over the life of the futures contract at time t–k. It follows that tests of cointegration between spot and future prices depends entirely on the time-series properties of the elements of a well-specified cost of carry model or, equivalently, differential given in equation (2). If the differential has a stochastic trend, then spot and futures prices will tend to drift apart and they would not be cointegrated. Conversely, if the differential is stationary, then spot and futures prices are tied together, and they would be cointegrated. Theoretically, in order to determine the way in which tests of market efficiency and cointegration are conducted in the literature, it is necessary to develop these results in the framework of a relevant no-arbitrage asset-pricing model (Bilson, 1981; Brenner & Kroner, 1995; Dwyer & Wallace, 1992).

The futures equilibrium, no-arbitrage model presented utilizes information contained in both the quality delivery option and convenience yield as a timing option in the NYMEX contract.[5] Futures contracts often offer the short position options on the quality, timing, location and quantity associated with physical delivery (see Boyle 1989; Cox, Ingersoll, & Ross 1981). In particular, recent studies by Gay and Manaster (1984) and MacDonald (2011, 2014) examine whether the presence of delivery options reduce the corresponding futures price.[6] The rationale is straightforward: if such options are valuable to the short, then a trader should be unable to acquire them without cost. Since the short never explicitly pays for these options, the futures price should be lower than it otherwise would be to compensate the long for the additional delivery risk. These delivery options are important because *all* market participants are subject to varying levels of delivery basis risk (Lien, 1988, 1991).

Following Brenner and Kroner (1995), the cointegration of spot and futures prices in the NYMEX crude oil market is tested here and shown to be consistent with a stationary differential as in equation (2). Previous studies of commodity markets have defined the differential in equation (2) as dependent solely on the stochastic properties of the domestic interest rate, which has led to what many researchers have termed the *trivariate cointegration paradox*.[7] That is, if spot and futures prices are cointegrated, and the domestic interest rate differential is non-stationary, then the rejection of the no-arbitrage hypothesis using cointegration analysis necessarily follows. The reason is that if spot and lagged futures prices are cointegrated and stationary, while the interest rate differential is non-stationary, then trivariate cointegration cannot hold. Of even greater importance is the fundamental notion that the law of one price must hold even when cointegration analysis yields opposing conclusions.[8]

The rest of this chapter is divided as follows. Section 2 presents the futures equilibrium model and Section 3 presents the no-arbitrage model and its relationship to tests of cointegration. Section 4 presents the data and Section 5 presents the empirical results. Finally, Section 6 contains conclusions and possible extensions for future research.

1. THE FUTURES EQUILIBRIUM NO-ARBITRAGE METHOD

On February 21, 2006 the NYMEX initiated the West Texas Intermediate/Brent (ICE) bullet swap. The NYMEX bullet swap (NYMEX/BY) futures contract provides for the simultaneous execution of opposing positions in the broad-based NYMEX (WTI/CL) crude oil futures contract and the narrow-based ICE (Brent/LO) crude oil contract. The NYMEX crude oil futures contract is a multiple (broad-based) delivery contract in which the short position can deliver either domestic crude streams based on the West Texas Intermediate (NYMEX/WTI) marker or foreign crude streams based on the international Brent (ICE/LO) marker. The ICE (Brent/LO) contract allows only for Brent (ICE/LO) deliverable crude streams.[9]

To derive a testable model for the broad-based NYMEX crude oil futures contract, first consider that the risk-neutral price dynamics of the adjusted (for delivery cost) spot WTI and Brent crude streams are governed by two correlated geometric Brownian motions with constant volatilities as in Margrabe (1978) and MacDonald (2011, 2014)

$$\frac{dS_{it}}{S_{it}} = \mu_i dt + \sigma_i dZ_{it},\ i = 1, 2 \tag{3}$$

where μ_i and σ_i are the instantaneous return and volatility of asset $i = 1, 2$. The dZ_{it} for asset $i = 1, 2$ are correlated Weiner processes with correlation coefficient ρ_{12}. Since the exchange option embedded in the futures contract does not trade in any market, its value must be estimated. In MacDonald (2011, 2014), the exchange option embedded in the NYMEX future contract was estimated using the Margrabe (1978) exchange option formula given by

$$W_t^c(T, S_{1t}, S_{2t}) = S_{1t}N(d_1) - S_{2t}N(d_2); \tag{4}$$

where $d_1 = \dfrac{\ln(S_{1t}) - \ln(S_{2t}) + 0.5\sigma^2(T-t)}{\sigma\sqrt{(T-t)}}$, $d_2 = d_1 - \sigma\sqrt{(T-t)}$,

and $\sigma = \sqrt{\sigma_1^2 + \sigma_2^2 - 2\rho_{12}\sigma_1\sigma_2}$

In equation (4), $N(\cdot)$ is the standard normal cumulative density function, $N(d_2)$ is the risk-neutral probability that the price of asset 2 will exceed the price of asset 1 at expiration and σ is the standard deviation of the difference between the rates of return on assets 1and 2. In the case of the call option, asset 2 is exchanged for asset 1 at expiration if the price of asset 1 exceeds that of asset 2; otherwise it expires worthless.[10]

MacDonald (2011, 2014) has shown that the following no-arbitrage stochastic exchange option equilibrium model can be derived:

$$W_t(T,\ S_{Bt}, S_{Wt}) = S_t(T) - e^{-r(T-t)}\{F_{Wt}(T) - F_{Bt}(T)\} \tag{5}$$

In equation (5), $W_t(T, S_{Bt}, S_{Wt})$ is the option to exchange WTI for Brent crude at maturity (time T) or contract maturity. S_{Bt} and S_{Wt} are the adjusted for delivery cost values of spot Brent (ICE/LO) and WTI (NYNMEX/CL) crude oil streams, $S_t(T)$ is the transactions costs associated with delivery and $\{F_{Wt}(T) - F_{Bt}(T)\}$ is the value of the NYMEX WTI/Brent bullet swap futures contract (NYMEX/BY). The value of the broad-based NYMEWX/WTI futures contract at time t maturing at time T is denoted as $F_{Wt}(T)$ and the price of the narrow-based Brent (ICE/LO) futures contract at time t maturing at time T is denoted as $F_{Bt}(T)$.

The discounted value of the NYMEX bullet swap $[e^{-r(T-t)}\{F_{Wt}(T) - F_{Bt}(T)\}]$ in the RHS of equation (5) will be positive whenever the delivery option to exchange the domestic marker (WTI) for the foreign marker (Brent) at time T [denoted by $W_t(T, S_{BT}, S_{WT})$] is less than the transportation, shipping and quality cost differential, $S_t(T)$. Note that at maturity when $t = T$, the value of the exchange option is the Max [0, $(S_{BT} - S_{WT})$] and $F_{BT}(T) = S_{BT}$ so that the following equation is obtained:

$$F_{WT}(T) = S_{BT} + e^{r(T-t)}\{S_T(T) - W_T(T, S_{BT}, S_{WT})\} \tag{6}$$

Since $S_T(T) = 0$, then

$$\begin{aligned} F_{WT}(T) &= S_{BT} - \max[(S_{BT} - S_{WT}), 0] \\ &= \min[S_{BT}, S_{WT}]. \end{aligned} \tag{7}$$

Equation (6) implies that the futures price at maturity will equal the spot price of the cheapest to deliver asset (allowing for grade, quality and transportation cost differentials).[11] Since the NYMEX WTI/Brent bullet swap is the difference in two futures prices, changes in the futures price spread will result from non-parallel movements in the underlying futures price series.

From equation (5), the value of the NYMEX WTI/Brent bullet swap futures price is:

$$\{F_{Wt}(T) - F_{Bt}(T)\} = e^{r(T-t)}\{S_t(T) - W_t(T, X_{Bt}, X_{Wt})\} \tag{8}$$

The LHS of equation (8) is the value of the NYMEX WTI-Brent bullet swap, which often trades at a *negative* value and is termed as a futures price inversion.[12] Although it is uncommon to think of a negative futures price, this is a *common occurrence* with the NYMEX WTI-Brent bullet swap. A negative value occurs whenever the exchange option value is greater than the transportation, grade and shipping costs. Since the shipping and transportation costs usually account for 5–10% of the underlying price of crude oil, a negative NYMEX bullet swap futures price implies that the quality exchange option must exceed this value.[13]

2. ARBITRAGE, COINTEGRATION AND THE FUTURES EQUILIBRIUM DIFFERENTIAL

Equation (5) implies that the NYMEX future price in the no-arbitrage framework is given as

$$F_{Wt}(T) = [S_{Bt}]\{Z_t(T)\}\{V_t(T)\} \tag{9}$$

where $Z_t(T) = 1 - \left[\dfrac{W_t\ (T, S_{Bt}, S_{Wt})}{S_{Bt}}\right]$ and $V_t(T) = e^{r(T-t)} + \left[\dfrac{F_{Bt}(T) - S'_{Bt} e^{r(T-t)}}{S_{Bt} - W_t(T, S_{Bt}, S_{Wt})}\right]$

and S'_{Bt} is the spot Brent price of crude delivered to Sullom-Voe and S_{Bt} includes delivery cost to Cushing, that is, $S_{Bt} - S'_{Bt} = S_{t,T}$. From the Margrabe (1978) put call parity (PCP) theorem[14]

$$F_{Wt}(T) = [S_{Wt}]\{Z_t'(T)\}\{V_t'(T)\} \tag{10}$$

where $Z_t'(T) = 1 - \left[\dfrac{W_t\ (T, S_{Wt}, S_{Bt})}{S_{Wt}}\right]$ and $V_t'(T) = e^{r(T-t)} + \left[\dfrac{F_{Bt}(T) - S_{Bt}' e^{r(T-t)}}{S_{Wt} - W_t(T, S_{Wt}, S_{Bt})}\right]$

$Z_t(T)$ and $Z_t'(T)$ are the respective exchange options and $V_t(T) = V_t'(T)$ is the interest adjusted basis (Fama & French, 1987; Ng & Pirrong, 1994) and r represents the continuously compounded risk-free rate of return.[15]

The terms $V_t(T)$ and $V_t'(T)$ in equations (9) and (10) are equivalent when the Margrabe (1978) PCP theorem holds (MacDonald, 2014) and is dependent on the convenience yield adjusted for interest costs.[16] The convenience yield is the difference between the value of the Brent futures price and the adjusted (for interest) Brent spot price for delivery at Sullom-Voe. The futures price could be greater or less than the spot price, depending on the magnitude of the net (of storage costs) marginal convenience yield. If the marginal convenience yield is large, the spot price will exceed the futures price and the futures market is said to exhibit *strong backwardation* $[F_{Bt}(T) < S_{Bt}]$. If the net marginal convenience yield is precisely zero, the spot price will equal the discounted future price $[F_{\mathrm{Bt}}(T) = e^{-r(T-t)}S_{Bt}]$. If the net marginal convenience yield is positive and the spot price is less than the futures price, but greater than the discounted future price, the futures market exhibits both the presence of *weak backwardation* $[S_{Bt} > F_{Bt}(T)e^{-r(T-t)}]$ and *contango* $[F_{Bt}(T) > S_{Bt}]$. Thus, contango includes the net differential between weak and strong backwardation $[F_{Bt}(T) > S_{Bt} > F_{Bt}(T)e^{-r(T-t)}]$ as a special case.

Since the Margrabe (1978) quality delivery options in equations (9) and (10) do not depend on the domestic risk-free interest rate, equations (9) and (10) are written in logarithmic form as:

$$LnF_{Wt}(T) = Ln[S_{Bt}] + Ln\{Z_t(T)\} + Ln\{V_t(T)\} \tag{11}$$

$$\text{and } LnF_{Wt}(T) = Ln(S_{Wt}) + Ln\{Z_t'(T)\} + Ln\{V_t(T)\} \tag{12}$$

If the spot and futures prices are cointegrated, respectively, then $Ln\{Z_t(T)\}$, $Ln\{Z_t'(T)\}$ and $Ln\{V_t(T)\}$ must be stationary I(0) variables. Brenner and Kroner (1995) argue that with cointegration between future and spot prices, the only testable implication of market efficiency is whether the differentials in equations (11) and (12) are stationary.

3. DATA

3.1. Adjusted Physical Spot/Futures Crude Oil Price Data

Daily spot price data for January 4, 2000–December 28, 2007 sample period for WTI Cushing and Brent physical crude oil are from the Energy Information Association (EIA) of the US Department of Energy. The international Brent crude stream and crude streams based on the Brent marker trade in the spot market, sold on the concept of "term contract." That is, the pricing formula is based on the "marker price" (Brent spot) plus Dated for Front Line (DFL) to reflect grade differentials and supply-demand differentials for different calendar periods for crude oil deliverable at Sullom-Voe, denoted previously as the unadjusted (for delivery costs to Cushing, OK) as S'_{Bt}.

The spot WTI price EIA data is based on Platt's crude price assessments for crude delivered at Cushing, Oklahoma and although Platt's physical crude oil assessments are widely used by the industry, the "flat" price formation was originated by the New York Mercantile Exchange (NYMEX). In the spot market, negotiations for physical crude will typically use NYMEX as a reference point, with bids/offers and contracts expressed as a differential to the futures price. Using these differentials, Platt's makes daily and in some cases intraday assessments of the price for various physical grades of crude oil. The actual price paid by posted price gathers typically deducts pipeline tariffs, insurance and related transaction and contractual costs to move WTI based crude oil. That is, the WTI marker price includes (is adjusted for) delivery costs for delivery of WTI spot crude to Cushing, OK.

The shipping and transportation cost data are from Worldscale Association (NYC) Inc. and Drewry Inc. shipping consultants for the costs of moving crude oil from Sullom-Voe to the US Gulf Coast for the full sample period. Worldscale Inc. publishes an annually revised scale of rates and differentials on almost every possible tanker voyage in the world. Spot charter rates negotiated in Worldscale terms are tariffs for the carriage of a single cargo from one specified port to another (including the return ballast journey) in the immediate future (generally within the next 4–6 weeks). The data reflect the nominal freight rate (in $/ton) for a standard size tanker with set specifications – 75,000 dwt, 14.5 knots laden at 55 tons/day bunker consumption, based on a round-trip voyage between two ports. This nominal rate is referred to as Worldscale 100 or as the "nominal flat rate." Negotiated rates are a nominal percentage of the printed freight rate for a given voyage and vessel type.[17] According to recent industry estimates, the cost of moving oil from Midland to the Cushing hub is approximately $0.45 per barrel, while moving oil from Houston through the Sun terminal in Nederland, Texas or the Seaway terminal in Freeport, Texas is approximately double this value at $0.90 and insurance was estimated at $0.03 per barrel. Treasury bill discount yields are from the St Louis Federal Reserve (FRED II).[18]

Transportation and shipping costs, as a percentage of the price of crude oil, are usually in 5–10% range over the sample period. Although shipping and transportation costs are relatively stable over short periods, they have tripled over the eight-year sample period. Conversely, the price of crude oil has increased more than five-fold during the same period, indicating that transportation costs generally have decreased as a relative percentage of the price of crude oil during the sample period. The transportation data also exhibit a moderate seasonal component. For the months of June and December (the long-term 72-month futures contracts), the transportation cost rises relative to prior months (usually in the 1–3% range). Transportation costs during the sample period were a relatively higher percentage of the price of crude oil when crude oil prices were relatively lower.[19]

3.2. NYMEX/Brent Futures Contract Specifications

The NYMEX future price and spot WTI and Brent crude prices adjusted for delivery costs on the first trading day of each delivery month are used as the best available forecast for the coming month. This procedure involves a trade-off in useable observations, but eliminates well-known problems associated with autocorrelation and bias associated with overlapping series. The full sample is based on 94 monthly observations for the period March 2000–December 2007 in which complete data are available. The NYMEX and Brent futures price data were obtained from RC Futures Data Inc. for the entire sample period (January 1, 2000–December 31, 2007).

The NYMEX/WTI futures contract allows the following deliverable domestic crude streams: West Texas Intermediate, Low Sweet Mix, New Mexican Sweet, North Texas Sweet, Oklahoma Sweet and South Texas Sweet.[20] These specific domestic crude oils with 0.42% sulfur by weight or less, not less than 37° American Petroleum Institute (API) gravity or more than 42° API gravity are deliverable. The NYMEX also provides for delivery of specific foreign crude oils of not less than 34° API or more than 42° API. The following foreign streams are deliverable at Cushing, OK: U.K. Brent, for which the seller shall receive a 30 cent per barrel discount below the final settlement price; Norwegian Oseberg Blend is delivered at a 55¢–per–barrel discount; Nigerian Bonny Light, Qua Iboe, and Colombian Cusiana are delivered at 15¢ premiums.[21] The Brent (LO/ICE) futures contract is for crude oil deliverable at Sullom-Voe and is a narrow-based contract.

Although the NYMEX future contract specifications allow for domestic delivery of multiple blends, there is no current value to the *within domestic* delivery quality option since posted price gathers pay the same price for equivalent NYMEX deliverable streams (see e.g. Plains Marketing LP). The *within* benchmark delivery option of foreign crude streams is also of importance and dependent on the correlation of adjusted deliverable foreign crude prices (see MacDonald (2011, 2014) for discussion on the exchange option).

4. EMPIRICAL ANALYSIS AND RESULTS

Table 1 presents the number of months within the sample in which the narrow-based Brent futures market is in weak backwardation [$e^{-r(T-t)}F_{Bt}(T) < S_{Bt}$], strong backwardation [$F_{Bt}(T)) < S_{Bt}$] and when an inversion in the futures price spread or negative NYMEX WTI/Brent bullet swap futures prices, [$F_{Wt}(T) - F_{Bt}(T)$] < 0, occurs. A strong backwardation occurs when the convenience yield more than compensates for storage and financing costs and a weak backwardation occurs when the convenience yield compensates for storage costs but not for financing costs. A weak backwardation occurs in the Brent market 52% of the time and a strong backwardation occurs 48% of the time. The convenience yield estimates are consistent with those presented by Gibson and Schwartz (1990), Considine and Larson (2001), and Litzenberger and Rabinowitz (1995). Finally, although not a violation of the no-arbitrage condition, negative values of the NYMEX bullet swap futures price are observed (15.5%), which implies that the option to exchange WTI for Brent (equation (5)) is increasing.