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Price spread and convenience yield behaviour in the international oil market

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This paper examines the price and volatility behaviour of two similar commodities (Brent Crude Oil and West Texas Intermediate) and attempts to identify the variables that affect their relative price differential. Price spreads and convenience yields are estimated in an effort to test a number of hypotheses relating to market segmentation, seasonality and maturity effect. Cash and futures price data covering the period 1991–1995 reveal that: convenience yields are significant and about 2.5% of cash prices on the average; convenience yields exhibit strong yearly and monthly seasonalities due to supply/demand imbalances; convenience yield is a negative function of the level of stocks and behaves like a call option; as maturity of futures contracts nears, their convenience yields get smaller, an indication that the maturity effect exists in futures prices, and crude oil price spreads are affected by convenience yields which act as surrogates for demand/supply conditions and market price behaviour.

I. INTRODUCTION

The globalization of international financial markets and twenty-four hour trading has changed dramatically the pattern of asset trading. This is especially the case for government securities and commodities such as gold and oil, which trade simultaneously on various international markets. Existent academic literature has tested the impact of simultaneous trading of securities co-listed in international markets (Alexander *et al*., 1987, Emanuel *et al*., 1987). Little research, however, has examined the issue of simultaneous commodity trading in international markets.

The purpose of this study is to examine the price and volatility behaviour of two similar commodities traded in two international markets: Brent crude oil and West Texas Intermediate (WTI) crude oil. Such an examination aims to provide a framework of analysis, which is unique to the study of real commodities as opposed to financial securities. Because of many factors specific to commodities (i.e. transportation cost, convenience yields, the movement of inventory levels, seasonal needs), riskless arbitrage between the two markets may never attain. This circumstance will result in a very volatile price spread between the two markets that may suggest partial market segmentation in an otherwise free international market. With the consideration of the above-mentioned factors, this paper will attempt to identify the variables that affect the relative pricing differential of these similar crude oils. Such investigation should improve our understanding of the workings of international commodity pricing and the extent of partial market segmentation. Hopefully, it will also offer invaluable insight for profitable trading strategies.

Crude oil is a strategic resource and one of the most important commodities to affect the global economy and international trade. While oil exploration and production is evidenced in many geologically different areas throughout the world, most of the futures trading takes place in two specific locations: New York City (New York Mercantile Exchange – NYMEX) and London (International Petroleum Exchange – IPE). Both exchanges facilitate the trading of oil for future delivery. NYMEX trades crude oil futures and options based on West Texas Intermediate (WTI) crude oil, while IPE trades the Brent Blend crude oil produced in the North Sea.

The history of futures markets suggests that no two markets trading the same or almost the same commodity may co-exist. In such a case, the most liquid market

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gradually attracts most of the trading while the less liquid market slowly disappears. Among many examples of exclusive futures markets are corn, soybeans, pork bellies, copper, gold, Treasury bills. Still even when one market is less liquid than the other, similar markets may exist as long as the marginal benefit from trading elsewhere, at a time when domestic trading is unavailable, is greater than the marginal costs of trading in a less liquid market. An example of such a market is the Eurodollar futures trading in the International Monetary Market of the Chicago Mercantile Exchange and the London International Financial Futures Exchange (LIFFE) and the Treasury Bonds traded in CBT and LIFFE. This type of trading has allowed Emanuel *et al*. (1987) to study the arbitrage gains from price differences in the two Treasury bonds markets. However, little research exists on the price differences and the arbitrage potential of similar commodities traded on different international markets.

This study analyses both cash and futures markets for Brent and WTI oils and provides estimates of convenience yields and examines their volatility through time and for major sources of seasonality. It is argued that the observed convenience yields are surrogates for the volatility level in the cash market and the changing conditions in the demand/supply of the commodity. An analysis of data variables is used to support this hypothesis. These relationships are also used to explain the variability in the price spreads.

The paper is organized as follows. Section II describes the nature and trading characteristics of Brent and WTI. Section III discusses existent evidence on the efficiency of futures oil markets. In Section IV the authors' hypothesis about the cross-sectional relationships among convenience yields, volatilities and price spreads is developed and the most important variables that can explain these relationships are described. The data and methodology followed are described in Sections V and VI, respectively. The empirical results are presented and analysed in Section VII and a summary and some concluding comments are offered in Sections VIII and IX, respectively.

II. THE TRADING AND THE NATURE OF WTI AND BRENT CRUDE OILS

Crude oil is a widely traded commodity mainly for its two primary products, gasoline and heating oil, which are indispensable for transportation, industrial and residential uses. Crude oil is also the source of motor oil, grease, tar and a variety of chemicals. Crude oil is pumped in many geologically different areas of the world. Its quality varies depending upon its content of sulphur and gravity. With respect to Brent and WTI, their quality characteristics of sulphur and gravity are fairly similar. The only quality difference is that WTI results in slightly more gasoline (more valuable) and slightly less heating oil (less valuable) than Brent. As a result, WTI enjoys a slight price advantage over Brent.

Brent is a North Sea crude oil that is extracted from different fields and through a pipeline. It becomes available for tanker loading at Sullum Voe on Shetland Islands. All major companies are involved in the distribution of Brent oil that is directed to other Western European ports for refinery and ultimate consumption. Besides the existence of a spot market for immediate delivery of specific physical cargoes, there are two widely variable markets: 15 day forward and Brent futures. The forward market is largely unregulated but rather liquid. Its participants are the large oil companies, oil traders, US investment banks, Japanese Trade Houses and others. Their agreements are private in nature although they know each other's forward positions. Such private agreements result in different prices within any day for the same contract size of 500 000 barrels. For this reason the IPE calculates the *Brent Index*, an average forward price with 15 days remaining for delivery. Contracts are customarily written for three to four months although some are for six months. The contract matures 15 days prior to the month of delivery to allow the buyers to arrange for the tanker to accept the delivery at Sullum Voe.

The Brent Oil Futures market is traded at the London's International Petroleum Exchange. These contracts are written in 500 000 barrels of Brent Oil. The settlement is through cash based on the Brent Index price on the tenth trading day of the month prior to the delivery month. The market is well organized although to reach its present state it had to undergo three major changes. The problems with the previous contracts (the first launched in 1983, the second in 1985 and the present contract in 1989) were related to delivery and contract size mis-specification.

WTI is a crude oil that is extracted from wells in the southern part of the USA and specifically Texas and Oklahoma. These wells are connected with a system of pipelines that result in Cushing, Oklahoma, the point of delivery for WTI. For a long time the market operated as a forward market among oil companies, traders, and speculators. Since 1983, however, futures contracts were introduced on the New York Mercantile Exchange. These contracts are written on 1000 barrels of WTI oil. Settlement is arranged with the delivery of the physical commodity. Futures trading stops on the third trading day prior to the 25th day of the month prior to the delivery month. This is done to inform which producers must make arrangements to have their oil delivered through the pipeline before the end of the delivery month. Despite early slow trading, the NYMEX WTI futures contract is heavily traded nowadays, and is an important vehicle for hedging and speculation. It should be noted that as in all futures contracts, a price limit is imposed on the trading of oil futures. Specifically, prices cannot rise or drop more than \$1 per barrel from the previous day's closing price.

III. FUTURES MARKET EFFICIENCY

Ever since Eugene Fama published his paper in 1970, the issue of market efficiency in capital and commodity markets has long been an interesting subject of study and debate. The efficient market hypothesis argues that observed prices reflect all available information. With respect to the futures markets this hypothesis means that observed futures prices fully incorporate all existing information which affect future spot prices.

A number of studies have examined the market efficiency of the WTI futures markets. Domininguez (1989) found evidence that during the first four years of trading (1983–1987), the WTI operated as an efficient market where futures prices not only reflect quickly any new issued information, but also form a good base for effective hedge against oil price risk. In a separate study, Ma (1989) has provided evidence that the NYMEX energy futures markets are efficient and improve the ability to forecast the future direction of prices. Bozorg *et al*. (1990) examined the reaction of WTI futures to the advent of public information by studying the nonstationarity of variance of the WTI futures price over 24 hour period. They found that the volatility of price changes is different during days with scheduled relevant public information releases than in days with no such releases. This finding was attributed partly to the trading that takes place in another market (IPE) while NYMEX is closed. The absence of Brent price data, however, prevented the authors from examining the entire behaviour of volatility within the 24 hour period and its implication on differences between the price structure of the markets.

Although no study of market efficiency on the newly reintroduced Brent futures market has been identified, industry participants regard this market as efficient. Indeed, this aspect of the market has been enhanced greatly by the recent increase in the volume of trading which resulted in a more liquid overall market. This increase in trading in Brent oil futures results from the need of interested parties to hedge non-US oil needs. Brent oil, by its geographical origin and refinery demands it is considered to move more in line to the world oil prices than WTI. As a result, it provides a hedging vehicle for participants, which are more concerned with international supply and demand of oil and the risk of such oil price changes.

The introduction of Brent futures has expanded the opportunities for hedging and speculation not only geographically but also within the 24 hour period. Although the co-movement of these two price series is far from perfect, the general price trends are similar. This allows traders to close a position in the other market if the market in which they opened the position was closed. This may happen at times with news which affects all oil prices across the board (i.e. the Iraqi invasion of Kuwait in August 1990 or its intervention in the Kurdish conflict in September 1996) and the availability of trading in the alternative market is very important. Of course, taking opposite positions in two different markets at different times or even simultaneously involves the risk of potentially significant changes in the spread. This study seeks to estimate that risk.

The existence of two similar oils in two different time zones allows participants to trade in the oil markets over an extensive period of time. Traders may trade oil futures in IPE beginning at 3:25 a.m. EST until 11:30 a.m. EST. However, starting at 9:45 a.m. EST they may also trade at NYMEX until 3:10 p.m. EST of the same day. So the only time that 'riskless' arbitrage may be exercised is between 9:45 a.m. and 11:30 a.m. EST when both futures markets are open. At all other times trading is available in only one market and is not available in either market for about 12 hours between 3:10 p.m. EST and 3:25 a.m. EST of the following trading day. Since relevant information on the oil markets is disseminated on a continuous basis, the closing prices on the two markets will not reflect the same information and therefore are not directly comparable. The only 'time' comparable prices are those obtained during the period that both markets trade. Unfortunately, however, use of such prices necessitates the need for intraday price data that cannot be obtained. As a result, the closing prices of the two markets that are 3 hours and 40 minutes apart will be used.

IV. FACTORS AFFECTING THE WTI/ BRENT FUTURES SPREAD

First, define the price spread between WTI Futures and Brent Futures prices in time t with maturity in time T, $SPR(t, T)$ as:

$$SPR(t, T) = FW(t, T) - FB(t, T) \tag{1}$$

where: $FW(t, T)$ is the futures price of a WTI contract at time t maturing at time T, and $FB(t, T)$ is the price of a Brent futures contract at time t with the same maturity as the WTI contract.

It follows that since many futures contracts with different deliveries are trading in each time t, we can evaluate an equal number of price spreads: $SPR\ (t, Ti)$ for $i = 1, \ldots, n$, where n is the number of available pairs (WTI/Brent) of futures contracts with delivery time i.

Since the price spread is the difference of two prices, changes in the price spread will result from non-parallel movements at either $FW(t, T)$ or $FB(t, T)$ or both. Demand for and supply of the underlying oil and its refined products will affect these prices, in turn. These are two of the variables that will determine the ultimate size of the spread. Below all possible variables that may affect the spread are discussed.

Temporary demand/supply divergences

Over time the US oil inventory levels may accumulate faster or slower than expected. To the extent that actual US demand for oil is not moving in the same direction as the oil inventory buildup, US oil prices (WTI) must change to achieve a new market equilibrium. If this divergence is of a temporary nature, however, prices in the Brent oil may not change. Similarly, temporary imbalances in the European market are not likely to induce changes in the WTI prices, *ceteris paribus*. Therefore, variations in inventory levels are likely to explain some variability in the price differential in the two markets.

Seasonal factors

The rate of change in the demand of and supply for oil is not kept constant throughout the year. If disruptions in production were to occur, they would probably occur during the winter months than during any other season. This is especially true for the Brent oil that is more vulnerable to extreme weather conditions. Demand for oil also has a seasonal component. During the summer months demand is affected by driving conditions, while during the winter months it is influenced by heating oil needs. This differential demand for two major products of crude oil (gasoline and heating oil) prompts refineries on a seasonal basis to alter their production accordingly. These seasonal factors are not likely to affect the two crude oils equally. Thus, a portion of variation in their price spread may be attributed to seasonalities.

Transportation costs

The costs of shipping oil from the delivery point to alternative refineries enter into the pricing structure of the oils under consideration. The WTI futures contract calls for oil delivery at Cushing, Oklahoma. Because this delivery point is closer to refineries than the delivery location for Brent (Sullum Voe, Shetland Islands), WTI has a slight price advantage over Brent. This further suggests that WTI is not likely to be shipped to European refineries. The same applies to Brent oil that is cheaper to ship to European refineries than to divert it to the USA. Therefore, as long as the transportation cost structure does not change, one should not expect to see any such influences affecting the price spread. Over longer periods of time, however, changes in the transportation cost structure will explain part of the volatility in the price spread.

Convenience yields

Convenience yield is the incremental value of spot prices over futures prices after accounting for carrying costs. Commodities with a flow of supply which is controlled by seasons (agriculturals) or production intensity (industrial metals) are susceptible to seasonal or occasional tightening of their supply. At such times because it is more valuable to own the spot commodity rather than a distant futures contract, a large continuous yield will appear. In the case of crude oil, significant convenience yields will exist because of supply disruptions due to related political events or accidents. Significant convenience yields in the WTI futures markets have been presented recently by Gibson and Schwartz (1990). Furthermore, there is a growing realization that convenience yields are stochastic and seasonal (Brennan, 1986; Fama and French, 1987; Heinkel *et al*., 1990; Milonas and Thomadakis, 1997a, 1997b). Milonas and Thomadakis have modelled convenience yields as call options written on a futures contract with expiration time some intermediate period prior to maturity and striking price, the maximum price that an intermediate futures can take given the expected available supplies then. This premise was verified empirically in four commodities: soybeans, corn, wheat and copper. If convenience yields are part of the observed futures prices in both Brent and WTI futures markets, their price spread will be due to the relative changes in the two convenience yields, *ceteris paribus*.

Volatility of the underlying cash commodity

One of the major findings of the Milonas and Thomadakis (1997a and 1997b) model is that the volatility of price changes of the underlying cash commodity is a major determinant of the variability in convenience yields. In fact, as in the case of call options, the greater the volatility in the cash commodity, the greater the chance that the cash price will exceed the futures price and thus the convenience yield will be greater. By affecting the size of convenience yields, the cash volatility is expected to affect the price spread directly.

The five variables mentioned above which are expected to affect the price spread are not completely independent from each other. In fact, convenience yield is the premier variable that captures in it all the other four variables. *Ceteris paribus*, convenience yield is expected to decrease by the building of production and inventories, the magnitude by which supply is greater than demand, the increase in the cost of inventories, and the decrease in the volatility of the underlying cash commodity, and vice versa. Conceivably the study of convenience yields alone may adequately explain the variability in the price spreads.

V. DATA

Daily closing Brent and WTI cash and futures prices, are available from International Limited Datastream for the period 2/01/91–1/31/96. From the same source three month Treasury bill yields have been used, over the same period. Finally, monthly oil statistics on the level of US stocks, strategic petroleum reserves, crude oil supply (domestic and imports) and disposition were available from the *Petroleum Supply Annual*, a publication of the US Energy and Information Administration/Monthly Energy Review.

VI. METHODOLOGY

Daily estimates of convenience yields have been calculated following Brennan (1986). The convenience yield $CY(t, T)$ is the difference at time t between the cash price of the underlying commodity (Brent or WTI), $C(t)$, and the time t futures price for contract maturity in time T, $F(t, T)$, after adjusting for carrying charges:

$$CY(t, T) = C(t) - F(t, T)e^{-TB(T-t)/365} \qquad (2)$$

where TB is the 3-month Treasury bill yield on an annual basis and $T - t$ is the time left until the futures contract matures. Since many futures contracts with multiple delivery dates trade on any particular day, multiple convenience yields can be calculated for day t.

The price spread will be calculated as in Equation 1 for those days for which data for both Brent and WTI futures with exactly the same maturity are available. Monthly estimates of the average spread and its volatility are estimated so that they can be associated with the available monthly data on the oil market. Based on monthly data various regression models are estimated that examine the relationship between convenience yields, spreads, volatilities, and oil supply and demand data.

VII. EMPIRICAL RESULTS

Distributional characteristics

Before proceeding with tests on convenience yields and spreads, the distributional characteristics of underlying cash data are examined in Table 1.

On the basis of 1304 observations that cover the sample period the distributional parameters of daily price levels and relative returns on Brent, WTI and their spread have been calculated. Over the period, WTI oil enjoyed an average \$1.29 premium on Brent oil per barrel, although, at times (as illustrated by the minimum value of spread) the premium disappeared and even became a discount. The returns on cash prices are slightly negative as they capture the gradual decline of prices from their high levels in January 1991, the time of the Gulf War conflict.

In the case of cash prices and spreads, the measure of kurtosis suggests that their distributions are not normal. To examine the issue of normality in the case of returns, a normality test was applied through the estimation of Chi-square.[1] In all cases, normality is rejected. Clearly, commodity price movements are affected by a number of sources that impose a non-stationary process in returns. Seasonality, time-to-maturity, and concentration of information on certain days (i.e. weekend) are the major factors causing nonstationarity.[2] Hall *et al.* (1989) have found that commodity price changes follow a combination of normal distributions with different variances, thus exhibiting non-constant variance. Yet, they did not analyse how the non-constant variance develops over time, a task assumed here.

Table 2 presents evidence of yearly and monthly seasonalities on logarithmic return volatilities. The average monthly standard deviations for each of the five years is shown in Panel A. The volatilities for 1991 and 1994 were the two highest and 1992 volatility was the lowest for both oils. While volatilities for the two oils are about similar order of magnitude, the correlation coefficient between volatilities of the two oils was only 0.76 suggesting significant independence of price movements between the two oils. However, most significant differences exist for the volatilities across years as evidenced by the ANOVA and Kruskal-Wallis test results. This suggests seasonality in returns due to events and conditions that are specific for a particular calendar year. Such an event, for example, related to concerns about available supplies in 1991, due to political events that took place in the Persian Gulf that helped push oil volatilities at their highest.

The time varying volatility found across years can be studied further by taking smaller time intervals. In Panel B of Table 2, data are arranged by calendar months and average monthly volatilities are presented. The winter months of January and February have the two highest volatilities while the month of October has the lowest volatility for both oils. The differences across months are significant as ANOVA tests suggest, yet according to Kruskal-Wallis tests, such statistical significance cannot be documented. The reason for this result is probably due to the existence of yearly seasonality that does not allow the monthly seasonality to reveal. To allow the study of monthly seasonality, the yearly seasonality is neutralized by normalizing monthly standard deviations by the average standard deviation for the year they are estimated. The average normalized standard deviations are shown in Panel B along with ANOVA and Kruskal-Wallis tests. Both tests on the normalized volatility data support the evidence of monthly seasonality along with yearly season-

[1] See Doornik and Hansen (1994) for the estimation technique of χ^2.
[2] See Anderson (1985), Milonas (1986), Kenyon *et al.* (1987), Doukas and Rahman (1986), for identifying non-stationarities in commodities.

Table 1. *Distributional characteristics time period: Feb. 1991–Jan. 1996* (*No. of daily observations: 1304*)

Cash price levels	Mean	Standard deviation	Skewness	Kurtosis	Minimum	Maximum	Chi-square*
Brent	17.84	1.95	−0.11	−0.12	12.8	23.00	
WTI	19.13	2.03	−0.24	−0.14	13.92	24.17	
Spread	1.29	0.48	0.07	5.09	−1.42	4.00	
Relative returns							
Brent	-4×10^{-5}	0.0164	−0.53	4.24	−0.11	0.06	53.62
WTI	-1.7×10^{-5}	0.0169	−0.11	6.16	−0.11	0.13	35.67
Spread	−0.0683	1.0381	20.27	472.77	−27.5	3.00	
Logarithmic returns							
Brent	-7.6×10^{-5}	0.0071	−0.68	4.91	−0.051	0.027	53.49
WTI	-6.9×10^{-5}	0.0073	−0.31	6.03	−0.049	0.054	34.16

Note: * the critical value of the chi-square distribution at 1% is 9.21.

Table 2. *Seasonality in return volatilities: average monthly standard deviation of logarithmic cash returns*

(A) The year effect in cash prices (59 observations)

Year	Raw standard deviations: Brent	Raw standard deviations: WTI
1991	0.0194	0.0184
1992	0.0117	0.0121
1993	0.0142	0.0144
1994	0.0181	0.0193
1995	0.0118	0.0152
Grand mean	0.0159	0.0155
Signif. level		
ANOVA	0.00	0.00
Kruskal–Wallis	0.00	0.01

(B) The month effect in cash prices (60 observations)

	Raw standard deviations		Normalized standard deviations	
Month	Brent	WTI	Brent	WTI
Jan	0.0204	0.0195	1.3917	1.2771
Feb	0.0212	0.0229	1.3274	1.4137
Mar	0.0192	0.0158	1.1806	0.9797
Apr	0.0157	0.0184	1.0340	1.1541
May	0.0128	0.0151	0.8478	0.9683
Jun	0.0126	0.0145	0.8393	0.8952
Jul	0.0145	0.0134	0.9371	0.8519
Aug	0.0142	0.0178	0.8933	1.1302
Sep	0.0139	0.0124	0.9122	0.7975
Oct	0.0117	0.0112	0.7728	0.7120
Nov	0.0144	0.0136	0.9637	0.8778
Dec	0.0150	0.0157	0.9784	0.9979
Sign. level				
ANOVA	0.00	0.00	0.00	0.00
Kruskal–Wallis	0.33	0.23	0.08	0.09

ality. This evidence of seasonality in oil prices will be taken into account as other empirical tests are applied below.

Daily data

Table 3 presents the means and the standard deviations of daily convenience yields for Brent and WTI expressed as $ per barrel as well as a percentage of the underlying cash price. The results are presented by the time remaining to maturity as well as when all maturities are included.

For the Brent oil futures, the average convenience yield is $0.47 or about 2.5% of the Brent oil cash price. On the other hand, the average WTI convenience yield is $0.45 or 2.1% of the WTI cash price. These figures suggest that the average convenience yields for the two oils are virtually identical, despite the fact that the average WTI cash price ($19.13) was higher than the Brent cash price per barrel ($17.84). This implies that Brent convenience yields represent a higher proportion of cash price than WTI convenience yields, a fact that is been validated by the results for each maturity and for the overall average of 2.5% for Brent versus 2.1% for WTI. This higher percentage of convenience yield per Brent cash price probably results from the fact that Brent oil supply is more susceptible to disruptions than WTI due to weather conditions.

Another important issue in Table 3 is the evidence that for both oils the convenience yields steadily increase. Convenience yields with one year from maturity are as many as 10 times the convenience yields that were close to maturity. This in essence means that the cash price and the near to maturity futures contracts are at least 50 cents more valuable than longer maturity contracts. While such phenomenon is typical to crop-related commodities in which available supplies cannot be adjusted within the crop cycle, it is not expected, at first for commodities with more flexible production process.

The rationale for convenience yields to decrease or become insignificant beyond two to three months stems from the nature of oil production and distribution. While

Table 3. *Daily convenience yields, time period: Feb. 1991–Jan. 1996*

Months from maturity	Brent crude oil					WTI crude oil				
	$ per barrel		% of Cash price			$ per barrel		% of cash price		
	Mean	St. dev.	Mean	St. dev.	Obs.	Mean	St. dev.	Mean	St. dev.	Obs.
1	0.11	0.31	0.006	0.02	1304	0.03	0.20	0.001	0.01	1304
2	0.23	0.49	0.012	0.03	1304	0.14	0.34	0.007	0.02	1304
3	0.31	0.64	0.016	0.03	1034	0.24	0.51	0.011	0.03	1034
4	0.38	0.75	0.020	0.04	1304	0.32	0.64	0.015	0.03	1034
5	0.44	0.82	0.022	0.04	1304	0.39	0.75	0.018	0.04	1034
6	0.49	0.87	0.025	0.05	1296	0.45	0.83	0.021	0.04	1034
7	0.48	0.85	0.024	0.05	1217	0.51	0.91	0.024	0.05	1034
8	0.53	0.92	0.027	0.05	1187	0.57	0.97	0.026	0.05	1034
9	0.58	0.99	0.029	0.06	1106	0.62	1.04	0.029	0.05	1034
10	1.09	0.79	0.062	0.04	475	0.67	1.09	0.031	0.06	1034
11	1.14	0.79	0.064	0.04	469	0.71	1.14	0.033	0.06	1034
12	1.14	0.82	0.065	0.04	425	0.74	1.18	0.034	0.06	1034
All mat.	0.47	0.81	0.025	0.04	12 695	0.45	0.80	0.021	0.04	15 648
F-value	32.08		38.63			33.66		38.74		
K-W value	77.15		83.57			74.88		76.00		

Note: All F-values and K-W values are statistically significant at 1% or lower.

the production of oil has no apparent cycle (like the production cycle of grains), yet oil is not available in the market immediately or on a short notice. Because the production of both Brent and WTI is channeled through a pipeline, reservations must be made for the use of the pipeline and a tanker must be commissioned to receive the oil at the port. The loading, shipping, and unloading of the ship could make the oil available at a minimum of one and a half months to a maximum of two to three months depending upon the destination point. Therefore, if there are news which force the price of crude oil to move higher, the holder of the crude oil (in a tanker, other facility, or in the pipeline) will be in an advantageous position over holding any futures contrasts maturing in the following two to three months. This advantage will lessen or disappear as arrangements can be made to own the cash commodity after three months. The futures prices should reflect this new information and convenience yields will all but disappear for the far maturing months.

Of course, it should be remembered that this rationale is valid as long as the production flow can be easily adjusted to meet the additional demand. However, in the case of oil, (whose demand is inelastic within a short and even a medium-range period), the supply flow is controlled both by the states as well as by the oil cartels. Although we deal with Brent and WTI oils that are not part of any cartel, international oil supply and prices are affected by the actions and policies followed by the OPEC nations. Furthermore, because of private agreements between individual countries and oil exporting countries, the flow of oil not only cannot increase in a short-period of time, but it cannot also be diverted from fulfilling long standing agreements. As a result, a large component in cash prices may account for the monopolistic power of OPEC as well as the speculation that prices could possibly move at extreme levels within a short period of time.

Seasonalities in daily data

Table 4 presents evidence on the seasonalities found in convenience yields. The daily convenience yield data are grouped in 12 categories one for each of the 12 months that were observed regardless of the maturity. It is hypothesized that due to supply disruption happening more often in the winter than in the summer months, the convenience yields would be different in different seasons and higher in the winter and early spring than in the summer and early fall.

The F-values and the non-parametric Kruskal-Wallis test values, reported at the bottom of Table 4, suggest that convenience yield levels are statistically different across the 12 months. For Brent oil the months from October to May, convenience yields, on the average, are greater than the summer months. For WTI, the general trend is that the summer months of June to September tend to have lower convenience yields than in the remaining months.

The seasonality found in Table 4 is not the only seasonality which exist. Another source of seasonality often is more prevalent (see Milonas and Vora, 1985; Milonas, 1991). This seasonality results from the fact that major political or economic events take place over an extended period of time and affect significantly all prices. Such an

Table 4. *The month effect in convenience yields, time period: Feb. 1991–Jan. 1996*

	Convenience yield means					
	Brent crude oil			WTI crude oil		
Months	$ Per barrel	Cash price (%)	Obs.	$ Per barrel	% of Cash price	Obs.
Jan.	$0.61	0.03	1110	$0.22	0.01	1320
Feb.	0.55	0.03	891	0.59	0.03	1200
Mar.	0.54	0.03	1014	0.33	0.02	1344
Apr.	0.70	0.04	991	0.61	0.03	1284
May	0.64	0.04	1046	0.60	0.03	1320
Jun.	0.37	0.02	1049	0.54	0.03	1296
Jul.	0.41	0.02	1080	0.56	0.03	1320
Aug.	0.22	0.01	1120	0.54	0.03	1332
Sep.	0.18	0.01	1094	0.38	0.02	1296
Oct.	0.50	0.03	1102	0.55	0.03	1308
Nov.	0.59	0.03	1098	0.42	0.02	1296
Dec.	0.34	0.02	1115	−0.03	−0.00	1296
All months	0.47	0.02	12710	0.45	0.02	15612
F-Value	33.46	38.70		33.72	38.75	
K-W Value	19.84	22.11		28.71	26.85	

Note: All F-Value and Kruskal–Wallis statistics are statistically significant at 5% or lower.

Table 5. *The year effect in convenience yields, time period: Feb. 1991–Dec. 1995*

	Convenience yield means					
	Brent crude oil			WTI crude oil		
Year	$ Per barrel	Cash price (%)	Obs.	$ Per barrel	% of Cash price	Obs.
1991	0.75	0.036	1786	1.60	0.074	5157
1992	0.37	0.019	2319	0.83	0.039	5736
1993	−0.41	−0.026	2340	−0.50	−0.031	5656
1994	0.42	0.024	2882	0.19	0.006	5677
1995	0.97	0.055	3111	1.02	0.055	6191
All Years	0.44	0.023	12 438	0.62	0.038	28 416
F-value	715.5	794.0		1495.6	1728.3	
K-W value	272.3	281.0		339.4	338.6	

Note: All F-value and Kruskal–Wallis statistics are statistically significant at 0.00%.

effect is commonly recognized as 'year effect' and is shown in Table 5.

Table 5 shows significant differences in the average convenience yields across the years of observations.[3] For both oils, 1991 and 1995 stand out as the years with the highest level of convenience yields. The smallest level occurred in 1993, and it was negative. As figures in Table 5 reveal, convenience yields change dramatically from one year to another. The relative change is similar to both Brent and WTI oils. These suggest that convenience yields are very sensitive to changes in market conditions and, overall, the oil market is not segmented, at least as it concerns Brent and WTI.

Correlations in daily data

Tables 6 and 7 exhibit evidence of correlations in daily data (arranged by time left to maturity) between the convenience yield and cash and futures prices. Except eleven cases in correlations of convenience yields with futures

[3] Note that the mean convenience yields across years is larger than the mean convenience yield across months in Table 4, in the case of WTI, because all 24 maturities are included.

Table 6. *Correlations of convenience yields with oil prices, Brent crude oil, time period: Feb. 1991–Jan. 1996*

Months from maturity	Obs.	Convenience yields as $ per barrel with		Convenience yields as % of cash price with	
		Cash price	Futures price	Cash price	Futures price
1	1304	0.16	0.00*	0.12	−0.04*
2	1304	0.25	0.01*	0.21	−0.03*
3	1304	0.34	0.02*	0.31	−0.01*
4	1304	0.40	0.03*	0.37	0.00*
5	1304	0.46	0.06	0.44	0.03*
6	1296	0.52	0.10	0.49	0.07
7	1217	0.56	0.16	0.53	0.13
8	1187	0.61	0.20	0.58	0.16
9	1106	0.64	0.21	0.61	0.17
10	475	0.91	0.26	0.89	0.21
11	469	0.93	0.29	0.92	0.25
12	425	0.94	0.29	0.92	0.24

Note: * Not statistically significant at 5% or lower.

Table 7. *Correlations of convenience yields with oil prices, WTI crude oil, time period: Feb. 1991–Jan. 1996*

Months from maturity	Obs.	Convenience yields as $ per barrel with		Convenience yields as % of cash price with	
		Cash price	Futures price	Cash price	Futures price
1	1304	0.07	0.00*	0.06	−0.01*
2	1304	0.28	0.13	0.27	0.11
3	1304	0.37	0.14	0.35	0.12
4	1304	0.44	0.15	0.43	0.13
5	1304	0.50	0.16	0.48	0.15
6	1304	0.55	0.18	0.54	0.17
7	1304	0.60	0.20	0.58	0.19
8	1304	0.63	0.22	0.62	0.20
9	1304	0.67	0.23	0.65	0.21
10	1304	0.70	0.24	0.67	0.22
11	1304	0.72	0.25	0.70	0.23
12	1304	0.74	0.26	0.72	0.23
13	1304	0.76	0.27	0.73	0.24
14	1304	0.77	0.28	0.75	0.25
15	1304	0.79	0.28	0.76	0.25
16	1304	0.80	0.29	0.77	0.26
17	1304	0.81	0.30	0.79	0.26
18	1091	0.81	0.27	0.79	0.24

Note: * Not statistically significant at 5% or lower.

prices, all presented correlations in both tables are statistically significant at 5% or better. As one might expect, convenience yields will likely correlate to both cash and futures prices by construction in Equation 2. However, what is of interest to note is that the correlations of convenience yields with cash prices are much greater than the correlations of convenience yields with futures prices. This arises basically from the fact that cash prices, in general and in this particular case, are more volatile than futures prices (see Milonas, 1986). In other words, cash price changes are greater than futures price changes for a given information shock. As a result, changes in convenience yields will be attributed more to changes in the cash prices than changes in the futures prices. This argument can be extended further to address the phenomenon of maturity effect found in futures markets.

Samuelson (1965) had long argued that deferred futures contracts are less volatile than near maturity contracts and that futures price volatility increases monotonically as time to maturity nears. Intuitively, this happens because as futures contracts draw nearer to maturity, they are forced to react much stronger to information shocks, due to the ultimate convergence of futures prices to cash prices upon maturity. Anderson (1985), Milonas (1986) and Fama and French (1978) have provided empirical support to this hypothesis for a large number of commodities and financial assets. For this hypothesis to be valid in the data, futures prices must increasingly correlate strongly with cash prices as maturity nears. Alternatively, the convenience yields should get smaller as maturity nears. This behaviour has been discussed and presented in Table 3 and supports this argument. Furthermore, as the convenience yield gets smaller with time to maturity due to closer movement of futures to cash prices, the correlations of convenience yields with both price series will generally decrease. The behaviour of correlations shown in Tables 6 and 7 provide support for this hypothesis and indirectly supports the existence of the maturity effect in crude oil futures markets.

Monthly data

Table 8 presents the descriptive statistics for all variables on which monthly data have been obtained or calculated. The monthly data used in this study are limited to 60 months in the period February 1991 to January 1996. In panel A statistics are shown for US crude oil stocks, strategic petroleum reserves, and their total amount. Also supply (production) variables (domestic, imported, and total) and monthly disposition are provided. Total supply and total disposition are very close to each other although on the average the disposition was higher than supply. A microanalysis of the behaviour of these variables reveals that in cases that disposition runs higher than the monthly supply, strategic petroleum reserves are drawn down to meet the demand but quickly are replenished in the following month so that the previous level is always maintained.

Table 8. *Descriptive statistics on monthly data, time period: Feb. 1991—Jan. 1996* (*No. of monthly observations: 60*)

Variable	Mean	St. dev.	Minimum	Maximum
A. Oil industry data (in millions of barrels)				
US stocks	333.3	12.3	303	356
Strategic petroleum reserves	581.8	9.8	568	592
Total US stocks	915.3	12.3	893	938
Domestic supply	6.9	0.3	6.4	7.6
Imported supply	6.6	0.7	5.1	8.0
Total supply	13.5	0.5	12.5	14.5
Total disposition	13.7	0.5	11.8	14.6
B. Oil price data ($ per barrel)				
Brent cash price	17.84	1.88	13.56	22.21
WTI cash price	19.13	1.97	14.53	23.25
(C) WTI/Brent spread data ($ per barrel)				
Cash spread	1.29	0.35	0.35	2.05
1 month spread	1.37	0.29	0.86	2.27
2 month spread	1.39	0.20	1.00	1.84
3 month spread	1.38	0.16	1.08	1.75
4 month spread	1.37	0.14	1.11	1.69
5 month spread	1.36	0.13	1.08	1.67
6 month spread	1.35	0.12	0.97	1.66
(D) Convenience yield spread data ($ per barrel)				
1 month CY spread	−0.08	0.23	−0.79	0.25
2 month CY spread	−0.09	0.28	−1.16	0.38
3 month CY spread	−0.08	0.33	−1.26	0.52
4 month CY spread	−0.07*	0.34	−1.15	0.66
5 month CY spread	−0.05*	0.35	−1.04	0.69
6 month CY spread	−0.04*	0.34	−0.98	0.63

Note: *Not statistically significant at 10% or lower

Table 9. *Correlations of monthly data among volatilities, convenience yields, and spread time period: Feb. 1991–Jan. 1996*

Months left to maturity	Variable	Variables: Brent conv. yield	WTI conv. yield	Price spread	Spread st. dev.
	Brent cash st. dev.	0.52	0.50	0.13*	0.70
	WTI cash st. dev.	0.31	0.46	0.08*	0.66
2	Spread st. dev.	0.58	0.58	0.18*	1.00
	Brent conv. yield	1.00	0.76	0.22	0.58
	WTI conv. yield	0.76	1.00	0.35	0.58
	Brent cash st. dev.	0.52	0.50	0.09*	0.66
	WTI cash st. dev.	0.32	0.44	−0.02*	0.65
3	Spread st. dev.	0.43	0.42	0.13*	1.00
	Brent conv. yield	1.00	0.82	0.24	0.43
	WTI conv. yield	0.82	1.00	0.21*	0.42
	Brent cash st. dev.	0.51	0.49	0.00*	0.56
	WTI cash st. dev.	0.32	0.42	−0.11*	0.54
4	Spread st. dev.	0.30	0.25	0.12*	1.00
	Brent conv. yield	1.00	0.86	0.16*	0.30
	WTI conv. yield	0.86	1.00	0.09*	0.25

Note: * Not statistically significant at 5% or lower.

In Panel B statistics were presented for Brent and WTI crude oil prices. As discussed in section II, the WTI prices should be higher than Brent because of its more valuable combination of sulphur/gravity contents. Indeed, results show WTI cash price to be $1.29 on the average higher than the Brent cash price. Furthermore, in terms of volatility, Brent seems to show similar volatility in prices.

In panel C the WTI/Brent average price spread is presented for cash and for matching futures contracts with 1 and up to 6 months left to maturity. The monthly average cash spread is $1.29 but over the 5-year period it fluctuates from as low as $0.35 to as high as $2.05. Furthermore, while the average one month futures spread is just $1.37, it is not different at longer maturities. What is striking, however, across months is the growing volatility of the spread as maturity nears, evidenced by the standard deviation and the increasing size of the range between maximum and minimum values of the spread.

Apparently underlying factors that affect the demand and/or supply of these two oils affect their price disproportionally and it becomes more evident near maturity. So while the spread level and fluctuation may be reasonable over the longer term, serious discrepancies from these levels may exist on any given day near maturity because demand cannot be met smoothly with available supplies. A cross sectional analysis of some of these variables which can potentially explain the variability in the spread for near maturity contracts is presented in the next section.

Finally, in Panel D the spreads between the convenience yields for matching maturity contracts are presented for up to six months from maturity. The negative and significant convenience yield spreads for the first three months suggests that the Brent convenience yield is greater than WTI. Beyond three months, however, convenience yield differences become insignificant. This evidence once more implies that the demand/supply divergences are likely to occur more often in the Brent market than in the WTI market possibly because of Brent production schedule susceptibility to weather conditions.

Cross-variable analysis

Table 9 presents the correlation structure between volatilities, convenience yields and price spreads. The correlations are reasonably strong among all variables examined. The relationship between convenience yields and the cash volatilities is strongly positive as is between the Brent and WTI convenience yields for spread maturities of 2, 3 and 4 months. While all correlations of volatilities with the price spread are small and insignificant, the correlation of price spread and its volatility and the convenience yields are positive and significant. This evidence suggests that the spread and its volatility relate directly to convenience yields and not to cash volatility. Perhaps, convenience yields behaving as call options already, have incorporated the cash volatility and there is no direct influence of cash volatility on spreads. This finding helps to design more appropriate regression models below.

To understand the influence of demand/supply factors on cash and futures prices, their impact on convenience yields, the derivative variable for cash and futures prices

Table 10. *Regression results, regression model 1:*

$$CYWTI\% = a_0 + a_1 D_{92} + a_2 D_{93} + a_3 D_{94} + a_4 D_{95} + a_5 \sigma_t + a_6 \ln(TOTST_t) + a_7 \ln(TOTSUP_t) + a_8 \ln(DISP_t) + e_t,$$

time period: Feb. 1991–Jan. 1996

Estimates	2	3	4	5	6
$\hat{a}_0$	2.012	2.550	2.54	2.328	2.134
	(2.50)*	(1.94)**	(1.49)	(1.15)	(0.93)
$\hat{a}_1$	−0.011	−0.017	−0.021	−0.023	−0.025
	(−2.65)*	(−2.56)*	(−2.42)*	(−2.25)*	(−2.13)*
$\hat{a}_2$	−0.021	−0.037	−0.052	−0.065	−0.076
	(−4.99)*	(−5.52)*	(−5.91)*	(−6.20)*	(−6.41)*
$\hat{a}_3$	−0.003	−0.010	−0.019	−0.028	−0.037
	(−0.76)	(−1.44)	(−2.06)*	(−2.55)*	(−2.92)*
$\hat{a}_4$	0.005	0.007	0.007	0.006	0.003
	(1.12)	(1.06)	(0.83)	(0.57)	(0.29)
$\hat{a}_5$	0.021	0.033	0.041	0.046	0.047
	(3.92)*	(3.83)*	(3.64)*	(3.42)*	(3.11)*
$\hat{a}_6$	−0.318	−0.413	−0.428	−0.413	−0.401
	(−2.66)*	(−2.12)*	(−1.70)**	(−1.38)	(−1.18)
$\hat{a}_7$	0.060	0.072	0.086	0.104	0.124
	(1.10)	(0.81)	(0.75)	(0.76)	(0.80)
$\hat{a}_8$	0.001	0.034	0.065	0.091	0.115
	(0.01)	(0.48)	(0.70)	(0.82)	(0.92)
Adjusted-R^2	0.62	0.63	0.62	0.62	0.61
F-Stat	13.11*	13.41*	13.27*	13.06*	12.68*

Note: σ = Standard deviation of logarithmic returns of WTI cash prices
CYWTI% = Convenience Yield of WTI as % of WTI cash prices
TOTST = Total US Stocks
TOTSUP = Total US Supply
DISP = Total Disposition
TOTST, TOTSUP, and DISP, are expressed in millions of barrels.
*Significant at 5% or lower.
**Significant at 10% or lower.

are examined. Table 10 shows the effect of cash price volatility (σ), total US stocks (TOTST), total available supply (TOTSUP) and total disposition (DISP), on the percentage convenience yield of WTI (CYWTI%) with 2, 3 and up to 6 months remaining to maturity. In all regressions these variables explain a good portion of the variability in WTI convenience yields. Furthermore, WTI cash price volatility and total US stocks have the right hypothesized sign and statistically significant coefficients. The other two variables that represent US demand and supply are not statistically significant.

The results of Table 10 give support to the traditional hypothesis of Working (1948), Telser (1958) and Brennan (1958) that convenience yield is a negative function of the level of stocks. Yet, it also provides support for the hypothesis that convenience yields behave like call options in line with recent evidence on other commodities.[4] Furthermore, the significant coefficients of the dummy variables suggest that non-stationarities due to specific events in a particular year have an independent influence on convenience yields which varies from one year to another.

Since convenience yields, as Table 10 shows, reflect the joint effect of demand and/or supply variables, it only needs the use of convenience yields to explain the variability in the price spreads. This will alleviate the problem of multicollinearity in the event that convenience yields along with demand and supply variables were to enter the equation as independent variables.

Table 11 presents the results for three regression models of convenience yields on price spreads. For price spreads with two months to maturity, the adjusted R-square for regression model 2 is 10% which suggests a reasonable explanation of price spread by the use of convenience yields of both Brent and WTI. Yet, only the WTI convenience yield is significant in explaining the variation in the spread. For regression models 3 and 4 statistical significance is observed for each convenience yield in explaining separately the variation in the spread for two and three months from maturity. Overall, as time from maturity lengthens, convenience yields explain less of the variation

[4] See Milonas and Thomadakis (1997a, 1997b).

Table 11. *Regression results, regression model 2:* $SPR_t = a_0 + a_1 CYBR_t + a_2 CYWTI_t + e_t$*, Regression model 3:* $SPR_t = a_0 + a_1 CYBR_t + u_t$*, Regression Model 4:* $SPRt = a_0 + a_2 CYWTI_t + v_t$*, time period: Feb. 1991–Jan. 1996*

Months from maturity	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$	Adjusted R^2	F-Stat.
	1.36	−0.05	0.30	0.10	4.15*
	(47.89)*	(−0.52)	(2.24)*		
2	1.362	0.104	—	0.03	3.07**
	(47.06)*	(1.75)**	—		
	1.35	—	0.249	0.11	8.13*
	(49.13)*	—	(2.85)*		
	1.36	0.055	0.020	0.02	1.74
	(56.26)*	(0.85)	(0.24)		
3	1.36	0.068	—	0.04	3.49**
	(57.08)*	(1.87)*	—		
	1.36	—	0.077	0.03	2.78**
	(57.51)*	—	(1.68)**		
	1.36	0.068	−0.047	0.00	1.07
	(65.73)*	(1.30)	(−0.78)		
4	1.36	0.033	—	0.01	1.53
	(66.11)*	(1.24)	—		
	1.37	—	0.020	−0.01	0.45
	(66.63)*	—	−(0.67)		

Notes: SPR = WTI futures price – Brent futures price
CYBR = $ Convenience Yield of Brent Oil
CYWTI = $ Convenience Yield of WTI Oil
t-Statistics are in parentheses.
*Significant at 5% or lower.
**Significant at the 10% level or lower.

in price spreads. This is in line with evidence in Table 6, Panel C where the price spread was found to have decreasing volatility with the lengthening of time to maturity. This suggests that for contracts four or more months away from maturity, price spreads are determined mainly by fundamental factors of quality differences between the two oils. In contrast, near maturity price spreads have convenience yield as an additional determinant. This determinant acts as a surrogate for demand/supply disparities and/or other events that influence the volatility of cash prices.

VIII. SUMMARY

In this paper we have examined the determinants of price spreads and convenience yields in two similar crude oils (Brent and WTI) traded in two important international markets (London and New York City). It has been hypothesized that prices of the two oils should be different due to their quality differences, but that the differences should not reach extremes if markets were to trade efficiently. Yet, due to particular conditions in the trading and nature of the two oils, temporary deviations cannot be ruled out. The behaviour of convenience yields and price spreads through time and for different maturity months were the two variables chosen to analyse the trading behaviour in the oil market.

The study of cash and futures price data in the period 1991–1995 revealed significant convenience yields that exhibit yearly and monthly seasonalities. These convenience yields correlate with cash prices much stronger than with futures prices, as expected. Furthermore, support was found on the traditional hypothesis that convenience yields relate negatively to oil stocks but that are positively affected by cash volatility. This provides additional support for recent arguments that convenience yields behave like call options. Finally, in additional empirical analysis involving oils stock and dispositions variables, price spreads were found to be affected by convenience yields which act as surrogates for demand/supply conditions and market price behaviour.

IX. CONCLUDING COMMENTS

From the overall analysis it appears that the oil market is characterized by large volatility on a monthly and especially yearly basis. The volatility in the price spread takes its highest values in the months near maturity. In fact, the daily volatility in the cash spread is about one sixth the price volatility of either oil while the average price spread is only one fourteenth the average oil price. These findings suggest that the two oil markets are not fully integrated and this cannot be overcome with the operation of riskless arbitrage. Because these two commodities' trading times overlap only for a few hours, simultaneous position taking is limited. Also, another obstacle for integration is that the delivery instruments differ. Furthermore, because the delivery of underlying commodity is costly, riskless arbitrage is not possible. This can be demonstrated also by the existence of large convenience yields and their large exhibited volatility. This makes spreading across the two contracts risky but promising. In fact, in our analysis we have shown in near maturity contracts a positive relationship between price spread and convenience yields and between the latter and volatility of cash prices. This behaviour suggests that traders should buy the spread (buy WTI and sell Brent) when it becomes obvious that the market enters a new era of price uncertainty and sell the spread (sell WTI and buy Brent) when this era of price uncertainty ends.

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