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"Market Efficiency of Oil Spot and Futures:
A Mean-Variance and Stochastic Dominance Approach"

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Abstract

This paper examines the market efficiency of oil spot and futures prices by using both mean-variance (MV) and stochastic dominance (SD) approaches. Based on the West Texas Intermediate crude oil data for the sample period of 1989-2008, we find no evidence of any MV and SD relationship between oil spot and futures indices. This infers that there is no arbitrage opportunity between these two markets, spot and futures do not dominate one another, investors are indifferent to investing in spot or futures, and the spot and futures oil markets are efficient and rational. Our empirical findings are robust to each sub-period before and after the crises for different crises, and also to portfolio diversification.

Keywords: Stochastic dominance, risk averter, oil futures market, market efficiency.

JEL Classifications: C14, G12, G15.

1. Introduction

Crude oil is an important commodity for the world economy. With the increasing fluctuations and tension of crude oil prices, oil futures have become one of the popular derivatives to hedge the risk of oil price hikes or crashes. Spot and futures prices of oil have been investigated over an extended period. Substantial research has been undertaken to analyze the relationship between spot and futures prices, and their associated returns. The efficient market hypothesis is crucial for understanding optimal decision-making with regard to hedging and speculation. It is also important for making financial decisions about the optimal allocation of portfolios of assets with regard to their multivariate returns and associated risks.

Research on the relationships between spot and futures prices of petroleum products has examined issues such as market efficiency and price discovery. Bopp and Sitzer (1987) find that futures prices have a significant positive contribution to past price changes, even when crude oil prices, inventory levels, weather, and other important variables are accounted for. Serletis and Banack (1990) use daily data for spot, two-month futures crude oil prices, and prices of gasoline and heating oil traded on the New York Mercantile Exchange (NYMEX), to test market efficiency, and they find evidence in support of the market efficiency hypothesis. In addition, Crowder and Hamid (1993) use co-integration analysis to test the simple efficiency hypothesis and the arbitrage condition for crude oil futures. Their results support the simple efficiency hypothesis that the expected returns from futures speculation in the oil futures market are zero.

Studies conducted during different time periods also provide insight. Between 1990 and 2000, Taback (2003) tests whether Brent spot and futures prices contain a unit root, and finds that both spot prices and futures prices are non-stationary. During the period 1989-2003, Coimbra and Esteves (2004) test the stationarity of Brent crude oil spot and futures prices which omit the impact of the Gulf war from January 1992 to December 2003. For both of these time periods, the null hypothesis of a unit root in crude oil prices cannot be rejected.

Recently, Maslyuk and Smyth (2008) use LM unit root tests with one and two structural breaks to show that oil spot and futures markets are efficient in the weak form. Their result suggests that future spot and futures prices cannot be predicted on the basis of previous prices.

Examining the price discovery process for the crude oil market using monthly data, Quan (1992) finds that the futures price does not play an important role in this process. Using daily data from NYMEX closing futures prices, Schwartz and Szakmary (1994) find that futures prices strongly dominate in the price discovery process relative to deliverable spots in all three petroleum markets. In addition, applying cointegration tests in a series of oil markets with pairwise comparisons on post-1990 data, Gulen (1999) concludes that oil markets have grown more unified during the period of 1994-1996 as compared with 1991-1994.

Postali and Picchetti (2006) apply unit root tests to examine international oil prices. They find that the traditional unit root tests reject the unit root null hypothesis for the entire sample of more than one century of annual data. Silvapulle and Moosa (1999) examine the daily spot and futures prices of West Texas Intermediate (WTI) crude by using both linear and non-linear causality testing. They find that linear causality testing reveals that futures prices lead spot prices, whereas non-linear causality testing reveals a bi-directional effect. Bekiros and Diks (2008) test the existence of linear and nonlinear causal lead–lag relationships between spot and futures prices of WTI crude oil. They discover strong bi-directional Granger causality between spot and futures prices, and that the pattern of leads and lags changes over time.

Lin and Tamvakis (2001) investigate information transmissions between the NYMEX and London's International Petroleum Exchange, and find that NYMEX is a true leader in the crude oil market. Investigating information transmissions among NYMEX WTI crude prices, NYMEX gasoline prices, NYMEX heating oil prices, and among international gasoline spot markets, including the Rotterdam and Singapore markets, Hammoudeh et al. (2003) conclude that the NYMEX gasoline market is the true leader. In addition, Hammoudeh and Li (2004) show that the NYMEX gasoline price is the gasoline leader in both pre- and post-Asian crisis periods.

Empirical studies indicate that commodity prices can be extremely volatile at times, and sudden changes in volatility are quite common in commodity markets. For example, using an iterative cumulative sum-of-squares approach, Wilson et al. (1996) document sudden changes in the unconditional variance in daily returns on one-month through six-month oil futures and relate these changes to exogenous shocks, such as unusual weather, political conflicts and changes in OPEC oil policies. Fong and See (2002) conclude that regime switching models provide a useful framework for studying factors behind the evolution of volatility and short-term volatility forecasts. In addition, Fong and See (2003) show that the regime switching model outperforms the standard GARCH model on all commonly-used evaluation criteria for short-term volatility forecasts.

In this paper, we re-examine the issue of market efficiency by applying the mean-variance and stochastic dominance approaches. We first apply the mean-variance (MV) criterion and CAPM statistics to analyse the oil spot and futures markets. These techniques have been used in much of the existing literature. Limitations of these approaches are that they are derived under the assumptions of a von Neumann and Morgenstern (1944) quadratic utility function and returns being normally distributed (Feldstein, 1969; Hanoch and Levy, 1969). Thus, the reliability of performance comparisons using the MV criterion and CAPM analysis depends on the degree of non-normality of the returns data and the nature of the (non-quadratic) utility functions (Beedles, 1979; Schwert, 1990; Fung and Hsieh, 1999).

In order to circumvent their limitations, we also use the stochastic dominance (SD) approach to compare the performance of different prospects. It endorses the minimum assumptions on investors' utility functions. The advantage of SD analysis over parametric tests becomes apparent when the asset returns distributions are non-normal. As the SD approach does not require any assumption about the nature of the distributions, it can be used for any type of distribution. In addition, SD rules offer superior criteria on prospects investment decisions since SD incorporates information on the entire returns distribution, rather than just the first two moments, as are used in the MV and CAPM methodologies. The SD approach has been regarded as one of the most useful tools to rank investment prospects (see, for example, Levy, 1992) as the ranking of the assets has been shown to be equivalent to utility maximization for the preferences of risk averters and risk seekers (Tesfatsion, 1976; Stoyan, 1983; Li and Wong, 1999).

Consider a utility-maximizing investor who holds a portfolio of two assets, namely oil spot and oil futures. The objective is to rank preferences of these two assets to maximize expected wealth and/or expected utility. In this paper, we use the SD test proposed by Linton et al. (hereafter LMW, 2005) to investigate the characteristics of the entire distributions of oil futures and spot returns, rather than considering only the mean and standard deviation, as are used in much of the existing literature.

This paper contributes to the energy economics literature in several ways. This is the first paper that discusses oil prices from the investors' perspective using the MV and SD approaches. Second, a more robust decision tool is used for examining investment decisions under uncertainty to the oil spot and futures markets in particular the WTI crude oil market. Third, greater information and inferences on investors' behaviour can be made, including the identification of any arbitrage opportunities in these markets, tests of market efficiency and market rationality in these markets, and an examination of the preferences of risk averters in these markets. Finally, we examine the impacts of OPEC's decision on reduction of production capacity in 1999, the effects of the 2003 Iraq War on these markets, and the diversification effects on these markets.

2. Data and methodology

We examine the efficiency of the spot-futures market by investigating the SD relationship between oil spot and its futures for the period January 1, 1989 to June 30, 2008. As it is well known (see, for example, Ripple and Moosa, 2005, 2007 and Serletis, 1992) that different maturities have an impact on market investment, hedging, efficiency and predictability, we will analyse the spot-future relationship for different maturities. We collect the WTI crude spot prices together with its futures at maturities of 1, 2, 3 and 4 months from the Energy Information Administration and analyze their relationships to check the effects of different maturities as well.

As is standard, the daily log returns, $R_{i,t}$, for the oil spot and futures prices are defined as $R_{i,t} = ln\ (P_{i,t} / P_{i,t\text{-}1})$, where $P_{i,t}$ is the daily price at day t for asset i, with $i = S$ (spot) and F (futures), respectively. We further examine the effects of two major oil crises (OPEC's decision on reduction of capacity in 1999 and the 2003 Iraq War) by examining two pairs of sub-periods. The first pair of sub-periods is the pre-OPEC sub-period (Pre-OPEC) and the sub-period thereafter (OPEC), using October 29, 1999 as a cut-off point, while the second pair of sub-periods is the pre-Iraq-War sub-period (pre-Iraq War) and the sub-period thereafter (Iraq War), using March 20, 2003 as the cut-off point.[1]

We display Figure 1 for the plots of WTI crude oil spot price with the corresponding cut-off points, and Figure 2 for the plots of WTI crude one month maturity[2] futures price with the corresponding cut-off points. The plots show that these markets could be efficient. In order to test this claim formally, we further analyse their relationship by the MV criterion, CAPM statistics, and the SD approach. For computing the CAPM statistics, we use the 3-month U.S. T-bill rate and the Morgan Stanley Capital International index (MSCI) to approximate the risk-free rate and the global market index, respectively.

2.1 Mean-Variance criterion and CAPM statistics

For comparative purposes, we first apply the MV and CAPM statistics to analyse the data. The MV model developed by Markowitz (1952) and Tobin (1958), and the CAPM statistics developed by Sharpe (1964), Treynor (1965) and Jensen (1969), are commonly used to compare investment prospects.[3] For any two investment prospects, with variables of returns Y_i and Y_j,

[1] We have examined other crises. Their effects on oil are similar to OPEC's decision and the 2003 Iraq War, but the magnitudes of their effects are less significant. Since OPEC's decision and the 2003 Iraq War are more strongly related to oil markets, the effects of only these crises are analysed in this paper.
[2] Figures for other maturity months are available upon request.
[3] We note that recently Leung and Wong (2008) have developed a multivariate Sharpe ratio statistic to test the hypothesis of the equality of multiple Sharpe ratios, whereas Bai et al. (2009a,b) have developed new bootstrap-corrected estimators of the optimal

means μ_i and μ_j, and standard deviations σ_i and σ_j, respectively, Y_j is said to dominate Y_i by the MV rule if $\mu_j \geq \mu_i$ and $\sigma_j \leq \sigma_i$ significantly (Markowitz, 1952; Tobin, 1958; Wong, 2007). CAPM statistics include the beta, Sharpe ratio, Treynor's index and Jensen (alpha) index to compare the performance of different prospects[4].

2.2 Stochastic Dominance Test

The SD theory, initially developed by Hadar and Russell (1969), Hanoch and Levy (1969) and Rothschild and Stiglitz (1970), is one of the most useful tools in investment decision-making under uncertainty to rank investment prospects. Let X and Y represent spot and futures, respectively, defined on the common support of $[a,b]$, where $a < b$ with their cumulative distribution functions (CDFs), F and G, and their corresponding probability density functions (PDFs), f and g, respectively. We define[5]

$$H_0 = h, \; H_j\left(x\right) = \int_a^x H_{j-1}\left(t\right)dt \tag{1}$$

for $h = f, g$; $H = F, G$; and $j = 1,2,3$. We call the integral H_j the j^{th} order cumulative distribution function (CDF).

The most commonly used SD rules that correspond with three broadly defined utility functions are first-, second- and third-order SD, denoted as FSD, SSD and TSD, respectively. All investors are non-satiated (that is, they prefer more to less) under FSD, non-satiated and risk-averse under SSD; and non-satiated, risk-averse and possessing decreasing absolute risk aversion (DARA) under TSD. We define the SD rules as follows (see Quirk and Saposnik, 1962; Fishburn, 1964; Hanoch and Levy, 1969; Sriboonchita et al., 2009):

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returns for the Markowitz mean-variance optimization.

[4] The formulae for the Sharpe ratio, Treynor index, and Jensen index are $S_i = \frac{R_i - R_f}{\sigma_i}$, $T_i = \frac{R_i - R_f}{\beta_i}$, and $J_i = \alpha_i = (R_i - R_f) - \beta_i(R_m - R_f)$, respectively (see Sharpe, 1964; Treynor, 1965; and Jensen, 1969 for further information on these statistics).

[5] See Wong and Chan (2008) for further discussion regarding notation.

X dominates Y by FSD (SSD, TSD), denoted by $X \succeq_1 Y$ $\left(X \succeq_2 Y, X \succeq_3 Y\right)$ *if and only if* $F_1(x) \le G_1(x)\left(F_2(x) \le G_2(x), F_3(x) \le G_3(x)\right)$ *for all possible returns* x in $[a,b]$, *and the strict inequality holds for at least one value of* x. *For TSD, we need one more rule which is* $\mu_F \ge \mu_G$ *where* $\mu_F = \int_a^b x dF(x)$ *and* $\mu_G = \int_a^b x dG(x)$.

The theory of SD is important as it is related to utility maximization (Quirk and Saposnik, 1962; Hanoch and Levy, 1969; Li and Wong, 1999). The existence of SD implies that risk-averse investors always obtain higher expected utilities when holding dominant assets than when holding dominated assets.[6] Consequently, dominant assets are preferred by investors. We note that a hierarchical relationship exists in SD: FSD implies SSD, which in turn implies TSD. However, the converse is not true: the existence of SSD does not imply the existence of FSD. Likewise, the existence of TSD does not imply the existence of SSD or FSD. Thus, only the lowest dominance order of SD is reported.

Finally, we note that, under certain regularity conditions[7], investment X stochastically dominates investment Y in first-order, if and only if there is an arbitrage opportunity between X and Y, such that investors will increase their expected wealth, as well as their expected utility, if their investments are shifted from Y to X (Bawa, 1978; Jarrow, 1986; Wong et al., 2008). In this situation, they could make huge profits by setting up zero-dollar portfolios to exploit this opportunity. On the other hand, if FSD does not exist between X and Y, one could conclude that both markets display market efficiency and market rationality (Bernard and Seyhun, 1997; Larsen and Resnick, 1999; Sriboonchita et al., 2009). We will discuss this issue in detail in the next subsection.

The advantages presented by SD have motivated prior studies using SD techniques to analyze many financial puzzles. There are two broad classes of SD tests: one is the

[6] The SD theory could be extended further to satisfy non-expected utilities (see Wong and Ma, 2008 and the references contained therein for further details).

[7] See Jarrow (1986) for the conditions.

minimum/maximum statistic, while the other is based on distribution values computed on a set of grid points. McFadden (1989) develops a SD test using the minimum/maximum statistic, followed by Klecan et al. (1991) and Kaur et al. (1994). Barrett and Donald (2003) develop a Kolmogorov-Smirnov-type test, and Linton et al. (2005) extend their work to relax the iid assumption. On the other hand, the SD tests developed by Anderson (1996, 2004) and Davidson and Duclos (hereafter DD, 2000) compare the underlying distributions at a finite number of grid points. The DD test is found to be one of the most powerful tests (see for example, Lean et al., 2008), and the LMW test is also found to be efficient. However, the DD test requires the iid assumption for the observations being analysed, whereas the LMW test allows general dependence among the prospects and also non-iid observations. As Tables 2A and 2B show that spot and futures are non-iid for both Brent and WTI crude spots and futures, we adopt the LMW test in this paper.

The SD test developed by Linton et al. (2005) is based on sub-sampling, and the resulting tests are consistent and powerful against some $N^{-1/2}$ local alternatives. The test statistic is:

$$T_j = \min \sup_x \sqrt{N\left[\hat{F}_j(x) - \hat{G}_j(x)\right]}$$

where

$$\hat{H}_j(x) = \frac{1}{N(j-1)!}\sum_{i=1}^{N}(x - z_i)_+^{j-1}, \quad H = F, G .$$

The LMW test evaluates the following two sets of null and alternative hypotheses:

$H_0 : F_j(x_i) \le G_j(x_i)$ for all x; and
$H_1 : F_j(x_i) > G_j(x_i)$ for some x.

$H_0^{'} : G_j(x_i) \le F_j(x_i)$ for all x; and
$H_1^{'} : G_j(x_i) > F_j(x_i)$ for some x.

The null hypothesis in H_0 states that the spot index dominates the futures index, while the null hypothesis in $H_0^{'}$ states that the futures index dominates the spot index. The alternative hypothesis is the SD relationship fails at some points. If we do not reject the first H_0 and reject the second $H_0^{'}$, this means that spot stochastically dominates futures at the j order. On the other hand, if we reject the first H_0 and do not reject the second $H_0^{'}$, this means that futures stochastically dominates spot at the j order. In addition, if we do not reject both H_0 and $H_0^{'}$, this says that there is no dominance between spot and futures, and the distributions of spot and futures are not rejected as being the same. Finally, if we reject both H_0 and $H_0^{'}$, this suggests that spot does not dominate futures and futures does not dominate spot, even though the distributions of spot and futures may not be the same.

2.3. Market Efficiency and Market Rationality

The conventional theory of market efficiency states that a market is considered inefficient and irrational if one is able to earn an abnormal return. Our focus here is how market efficiency and market rationality can be inferred by using SD rules to examine the existence of arbitrage opportunities, market efficiency and the rationality of investors, without identifying any risk index or specific model. By examining market data, SD answers the following queries: (a) Can investors increase their (expected) wealth by switching their portfolio choice, say from the oil spot to the oil futures or vice-versa? (b) Can risk-averse investors who switch from oil spot to oil futures increase their expected utility?

If all non-satiated investors can switch among their investment choices, say by selling spot and longing futures, and increase their (expected) wealth, then independently of their specific preferences, investors can benefit, and hence we could infer the market to be inefficient and irrational. Jarrow (1986) and Falk and Levy (1989) claim that, if FSD exists, under certain conditions arbitrage opportunities exist, and investors will increase their wealth and expected utility if they shift from holding the dominated asset to the dominant one. On the other hand, Wong et al. (2008) claim that, if FSD exists statistically, arbitrage opportunities may not exist, but investors can increase their expected wealth and expected utility if they shift from holding the dominated asset to the dominant one.

In addition, if the market is not 'complete,' even if FSD exists, investors may not be able to exploit any arbitrage opportunities.[8] If the SD test detects FSD of a particular asset over another, but the dominance only lasts for a short period, the results cannot be used to reject market efficiency or market rationality.[9] In general, FSD should not last for a very long period of time because market forces induce adjustments to a condition of no FSD if the market is rational and efficient. For example, if oil futures stochastically dominate oil spot at the first order, then investors would buy oil futures and sell oil spot. This will drive up the price of oil futures relative to oil spot until the market price of oil futures relative to oil spot is high enough to make the marginal investor indifferent between them. If new information is either made public quickly or is anticipated, the opportunity to use the new information to earn abnormal returns is of limited value. This idea changes slightly in a world where utility functions and returns distributions are not as severely circumscribed. If the FSD does not last for a long period of time, we infer that the market is still efficient and rational. However, in a situation where the FSD holds for a long period of time and all investors increase their expected wealth by switching their asset choices, the market would be neither efficient nor rational.

On the other hand, Falk and Levy (1989) claim that, given two assets, F and S, if by switching from S to F (or by selling S short and holding F long), an investor can increase expected utility, so that the market is inefficient. SSD does not imply any arbitrage opportunity, but implies the preference of one asset over another by risk-averse investors. For example, if oil futures dominate oil spot by SSD, one would not make an expected profit by switching from spot to futures, but switching would allow risk-averse investors to increase their expected utility. A similar argument can be made for the TSD criterion, which assumes that all investors' utility functions exhibit non-satiation, risk aversion, and decreasing absolute risk aversion (DARA).

If oil futures TSD oil spot, one would not make an expected profit by switching from spot to futures, but switching would allow risk-averse investors with DARA to increase their expected

[8] See Jarrow (1986), Wong et al. (2008), and Sriboonchita et al. (2009) for further discussion.
[9] See Falk and Levy (1989), Bernard and Seyhun (1997) and Larsen and Resnick (1999) for further discussion.

utility. Therefore, one could claim that the market is inefficient if investors are assumed to be risk averse and possess DARA. If no SSD is found in the market containing S and F, this suggests that risk-averse investors are indifferent between S and F, so they will not switch S to F, or vice-versa, to increase their expected utility. In this situation, we claim that the market is rational and efficient. Similarly, if no TSD is found in the market containing S and F, this says that risk-averse investors who possess DARA are indifferent between S and F. In this situation, we claim that the market is both rational and efficient.

3. Empirical results and discussion

[Insert Table 1 here]

Table 1 provides the descriptive statistics for the daily returns of both oil spot and futures prices for the entire sample period. It is showed that the daily returns of WTI crude oil futures have a higher mean and smaller standard deviation than those of WTI crude oil spot, especially for longer maturity, implying WTI oil futures dominate their spot according to the mean-variance criterion, especially for longer maturity. However, the paired t tests reveal that the mean differences of the spot returns and their corresponding futures returns are insignificant, while the F statistic shows that the standard deviations of the spot returns and their corresponding futures returns are also insignificant. These results indicate that the mean-variance criterion does not imply any dominance between spot and futures for Brent and WTI crude oil.

For the CAPM measures, all betas are negative and are less than one in absolute value. Based on the annualized Sharpe ratio, the futures outperform spot, especially for longer maturity. However, the Sharpe ratio test (Leung and Wong, 2008) shows that their differences are insignificant. Similarly, the test statistics[10] reveal that the annualized Jensen and Treynor indices of the spots and their corresponding futures are insignificant, suggesting that the CAPM statistics

[10] Refer to Appendix 1 for the statistical test.

fail to demonstrate any strong preference between the spot and futures markets. The inference drawn from the MV and CAPM statistics suggests that the spot and futures markets are efficient and rational.

[Insert Tables 2 and 3 here]

However, so far there is no strong linkage between market efficiency and the inferences drawn from MV and CAPM. In order to obtain a more accurate inference, we use the SD approach to examine the spot and futures markets. The results of the Ljung-Box statistics based on levels and squared levels of returns of spot and futures displayed in Table 2A, and the results of the Lo and MacKinlay (1988) variance ratio test statistics displayed in Table 2B, show that both spot and futures are non-iid. Thus, we cannot employ the SD test developed by Davidson and Duclos (2000) to analyse the spot and futures returns because DD test relies on the iid assumption. In this connection, we adopt the SD test developed by Linton et al. (2005) in the paper as this test can be applied to both iid and non-iid observations.

The results of the LMW test are displayed in Table 3. As the p-values are all bigger than the 10% significance level for both H_0 and $H_0^{'}$, this shows that (1) there is no arbitrage opportunity between spot and futures oil, (2) spot does not dominate futures significantly and vice versa, (3) investors are indifferent from investing in spot or futures, and (4) the spot and futures oil markets are efficient and rational for WTI crude oil.

3.1 The Impact of Oil Crises

The oil market is very sensitive not only to news, but also to the expectation of news (Maslyuk and Smyth, 2008). For example, when the OPEC countries agreed to reduce the combined production of crude oil in 1999, oil prices increased further. Similarly, the Iraq War, otherwise known as the second Gulf War, occurred in March 2003, also caused oil futures prices to increase further due to the fear that the Iraqi oil fields and pipelines might be destroyed during the war.

We use regression analysis, with the cut-off points of the crises being stated in the previous section as dummies, and find that the dummies affect both spot and futures in the Iraq War crisis but not in the OPEC crisis, indicating that the impact of war is greater for both spot and futures markets.[11] However, the impact of the war could not be used to draw a reference for the preferences and the performance between spot and futures and draw inference on market efficiency. To this end, we use the SD tests to analyse the returns series for the pre- and OPEC, and pre- and Iraq-War, sub-periods.

[Insert Table 4 here]

Before we conduct SD tests on the oil market, we first apply the MV criterion and CAPM statistics on the series. The results are reported in Table 4 each sub-period. As most of the results of the MV criterion and CAPM statistics for all the sub-periods are similar to those for the entire full sample period, we discuss only those results that are different from the full sample period. First, as compared with the pre-OPEC sub-period, the means for both spot and futures returns in the OPEC sub-period dramatically increased five-fold. However, as compared with the pre-Iraq-War sub-period, the spot and futures returns in the Iraq-War sub-period dramatically increased more than six-fold. Nonetheless, the differences between the means of spot and futures in each sub-period are not significant. In addition, the standard deviations for the returns of spot and futures are also not significantly different in each of the sub-periods. Thus, similar to the inferences for the entire sample, the MV criterion is unable to indicate any preference between the spot and futures markets. In addition, the CAPM statistics are unable to indicate any preference between the spot and futures markets.

[11] Detailed results are available on request.

We now apply SD to examine the performance of the spot and futures markets in all the sub-periods. The results from Table 3 show that all the p-values of the LMW test are greater than the 10% significance level, thereby leading to the same conclusion as for the entire period. Hence, these empirical evidences infer that the spot and futures indices do not dominate each other or in other words investors in this market are indifferent from investing in spot or futures. Furthermore, the LMW test result also implies that the WTI spot and futures crude oil markets are efficient and rational as well as no arbitrage opportunity between spot and futures oil in any of the sub-periods.

3.2 Robust Test on Diversification

[Insert Table 5 here]

Academics and practitioners are interested in examining investors' diversification preferences (Samuelson, 1967; Egozcue and Wong, 2010) in oil spot and futures markets. In order to achieve this purpose, we examine the dominance of spot or futures with the portfolios of different convex combinations of spot and futures, and report the p-values of the corresponding LMW test results in Table 5[12].

We first compare the full 100% of oil futures as one portfolio, with another portfolio consisting of different weights, from 10% to 90%, of oil spot and futures. If the weight of oil spot is x%, then the weight of oil futures is (100-x)%. Thereafter, we also compare the full 100% of oil spot as one portfolio, with another portfolio consisting of different weight of oil spot and futures, from 10% to 90%.[13] The same weight method is applied. The first row, second column shows the pairwise comparison for 100% of oil futures, with 10% oil spot plus 90% oil futures, and so on. The results are reported in Table 5. From this table, we draw the same conclusion as in

[12] As the results are qualitatively similar, we only report the results for futures with one month maturity. Results for other maturity months are available upon request.

[13] We also compare the preferences of different convex combinations of spot and futures prices. As the empirical results yield the same conclusion, we do not report these results.

comparing spot and futures, namely that we cannot find any significant evidence of SD between any pair of portfolios. In short, the diversification results in Table 5 are consistent with the results of spot and futures without diversification. This provides evidence to support that the WTI crude oil spot and futures markets are efficient at least for the sample period of the study.

4. Conclusions

This paper introduces the SD approach to examine the performance of spot and futures, and investors' behaviour in these markets, by analysing the entire period and the sub-periods, as well as different convex combinations of the portfolios of spot and futures. Our empirical findings suggest that there is no arbitrage opportunity between spot and futures oil, spot and futures do not dominate one another, investors are indifferent from investing in spot or futures, and the spot and futures oil markets are efficient and rational for the WTI crude oil markets.

We note that Moosa and Al-Luoghani (1995) show that both arbitrage and speculation play a role in determining oil futures prices, but the role of arbitrage is dominant. Our result of no arbitrage opportunity in these markets is contrary to Moosa and Al-Luoghani (1995). This could arise from the different methodology used by Moosa and Al-Luoghani (1995), or it may be due to the shorter period they examined, namely January 1986 to December 1991. As we have discussed in Section 2.3, in a short period, there may exist arbitrage opportunities. If the market is efficient, arbitrage opportunities will disappear in the long run.

It should be noted that the MV approach and the CAPM statistics used in the paper have a limitation in that they require the assumption of normality. One may consider applying other techniques, such as the established CAPM-MV theory with non-Gaussian errors (for example, Student-t or multi-modal mixtures of normals) (Chamberlain, 1983; Beaulieu et. al., 2007), Value-at-Risk (VaR) and CVaR are other measures for selecting investment positions. We note that the conclusions drawn from the SD and MV results in the paper are consistent. In addition, the conclusion drawn from SD is equivalent to many other non-normal approaches. For example, it is well known that the finding from FSD is equivalent to that from VaR, and the finding from SSD is equivalent to that from CVaR (Ogryczak and Ruszczynski, 2002; Leitner, 2005; Ma and Wong, 2006). Thus, it is not necessary to consider other non-normal approaches.

In addition, one could also consider examining other SD relationships, such as descending SD (DSD) for risk seekers (Li and Wong, 1999; Wong and Li, 1999), and the prospect SD (PSD) and Markowitz SD (MSD) models for investors with S-shaped and reverse S-shaped utilities, respectively (Levy, 2002, 2004; Wong and Ma, 2008). We do not conduct these alternative approaches because, when no SD relationship is found using the traditional SD approach for risk averters, the conclusions drawn from DSD, MSD, and PSD are equivalent to those drawn from traditional SD for risk averters (Sriboonchita et al., 2009).

Finally, we note that the SD approach introduced in this paper provides useful information to investors for decision making in oil markets. However, investors could also apply other techniques to study the market to provide additional information. For example, Silvapulle and Moosa (1999) find a bidirectional nonlinear causality effect between oil spot and futures prices, thereby suggesting that both markets react simultaneously to new information. Although SD approach does not provide such causality information, the causality test also cannot provide information drawn from the SD approach. Thus, if one would like to draw a more complete picture about oil markets, they should apply a wider range of tools to analyse the market.

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Table 1: Descriptive Statistics for Returns of Spot and Futures, 1989-2008

Variable	Spot	F1	F2	F3	F4
Mean (%)	0.0417	0.0417	0.0425	0.043	0.0433*
Std Dev	0.0243	0.0234	0.0204	0.0187	0.0177
Skewness	-1.1932***	-1.2878***	-1.5021***	-1.3012***	-1.0969***
Kurtosis	20.7355***	21.4867***	27.7857***	21.2559***	16.3703***
Jarque-Bera (J-B)	90907***	97721***	162983***	95691***	56924***
Beta	-0.1544	-0.1749	-0.1292	-0.1133	-0.1079
Sharpe Ratio	2.6571	2.7846	3.2604	3.6188	3.8651
Treynor Index	-0.425	-0.375	-0.525	-0.6	-0.65
Jensen Index	0.075	0.075	0.075	0.075	0.075
Pair t-statistic		-0.0047	-0.0170	-0.0268	-0.0345
F Statistics		1.0808	1.4176	1.6937	1.8856

Note: *, **, *** denote significance at the 10%, 5%, and 1% levels, respectively, and F1, F2, F3 and F4 refer to oil futures with 1, 2, 3 and 4 month's maturity date, respectively. The pair t-statistic tests for the mean equality between spot and futures. The F statistic tests for the equality of variances between spot and futures. Readers may refer to footnote 3 for the formulae of the Sharpe Ratio, Treynor Index, and Jensen Index. The reported values of the Sharpe Ratio, Treynor Index, and Jensen Index are all annualized.

Table 2A: Results of Ljung-Box tests for the Returns of Spot and Futures

		Spot	F1	F2	F3	F4
lag=5	LB test	35.60	34.48	16.78	12.39	10.94
	p-value	0.00	0.00	0.00	0.03	0.05
	LB^2 test	198.00	278.94	124.04	64.06	92.56
	p-value	0.00	0.00	0.00	0.00	0.00
lag=10	LB test	46.00	49.44	32.06	25.16	23.90
	p-value	0.00	0.00	0.00	0.01	0.01
	LB^2 test	259.75	310.71	155.22	80.43	118.27
	p-value	0.00	0.00	0.00	0.00	0.00

Note: F1, F2, F3, and F4 refer to the oil futures with 1, 2, 3, and 4 month's maturity date, respectively. LB and LB^2 are the Ljung-Box statistic based on the levels and squared levels of the time series, respectively. Both of them are asymptotically chi-square distributed with degree of freedom equals to the lag length.

Table 2B: Lo-MacKinlay Variance Ratio Test Statistics for the Returns of Spot and Futures

k	Spot	F1	F2	F3	F4
5	-4.153***	-3.545***	-2.129**	-1.719*	-2.605***
10	-4.960***	-4.390***	-2.947***	-2.527***	-3.012***
20	-4.186***	-3.685***	-2.410***	-1.993**	-2.272***
30	-3.264***	-2.812***	-1.652*	-1.213	-1.406

Note: *, **, *** represent significance levels of 10%, 5%, 1%, respectively. k is the duration period. Under the null hypothesis of iid, the Lo-MacKinlay variance ratio statistic follows the standard normal distribution asymptotically for any duration period k.

Table 3: Results of LMW Test for the Returns of Spot and Futures

	S > F1		F1 > S	
	FSD	SSD	FSD	SSD
Whole Period	0.8182	0.4665	0.7862	0.5195
Pre-OPEC	0.8501	0.5534	0.7463	0.4965
OPEC	0.9620	0.6114	0.9401	0.5345
Pre-Iraq	0.8681	0.5684	0.7782	0.4885
Iraq War	0.8941	0.7203	0.9660	0.6284
	S > F2		F2 > S	
Whole Period	0.7393	0.4965	0.6653	0.4995
Pre-OPEC	0.7692	0.5195	0.7592	0.4905
OPEC	0.7992	0.5305	0.8771	0.4975
Pre-Iraq	0.8362	0.5115	0.7333	0.4865
Iraq War	0.8771	0.5335	0.8881	0.5115
	S > F3		F3 > S	
Whole Period	0.7792	0.5065	0.6713	0.5005
Pre-OPEC	0.62138	0.5185	0.7572	0.4815
OPEC	0.8162	0.5155	0.7992	0.4955
Pre-Iraq	0.6234	0.4945	0.7443	0.5035
Iraq War	0.8511	0.5345	0.8142	0.5015
	S > F4		F4 > S	
Whole Period	0.7582	0.5095	0.6983	0.5045
Pre-OPEC	0.6294	0.5275	0.6484	0.4935
OPEC	0.7722	0.5115	0.7572	0.4935
Pre-Iraq	0.6074	0.4835	0.6943	0.5075
Iraq War	0.7522	0.5285	0.7223	0.5115

Note: The table displays the p-values of the LMW test. Readers may refer to Linton et al. (2005) for the LMW test statistics. F1, F2, F3, and F4 refer to oil futures with 1, 2, 3, and 4 month's maturity date, respectively.

Table 4: Descriptive Statistics for the Returns of Spot and Futures in Sub-Periods

	Variable	Spot	F1	F2	F3	F4
Pre-OPEC	Mean (%)	0.0078	0.0080	0.0093	0.0100	0.0099
	Std Dev	0.0248	0.0240	0.0201	0.0180	0.0167
	Skewness	-1.6449***	-1.8059***	-2.5034***	-2.3260***	-1.9327***
	Kurtosis	31.7345***	33.1100***	51.1408***	42.4780***	33.3643***
	J-B	117864***	128450***	305742***	211439***	130627***
	Beta	-0.3950	-0.3964	-0.3144	-0.2910	-0.2751
	Sharpe Ratio	-1.3967	-1.3639	-1.4367	-1.4738	-1.5606
	Treynor Index	0.0897	0.0844	0.0937	0.0929	0.0966
	Jensen Index	-0.0215	-0.0195	-0.0184	-0.0168	-0.0169
	F Statistics		1.0706	1.5265	1.9022	2.2063
OPEC	Mean (%)	0.0839*	0.0837*	0.0838*	0.0841**	0.0848**
	Std Dev	0.0237	0.0226	0.0208	0.0195	0.0189
	Skewness	-0.5397***	-0.5105***	-0.3894***	-0.3048***	-0.3800***
	Kurtosis	4.0572***	2.9623***	2.5129***	1.7668***	2.8456***
	J-B	1637***	912***	643***	324***	806***
	Beta	0.0283	-0.0065	0.0117	0.0221	0.0196
	Sharpe Ratio	8.0095	8.3306	8.9527	9.5226	9.9091
	Treynor Index	6.7968	-29.4778	16.2058	8.5441	9.6967
	Jensen Index	0.1933	0.1911	0.1898	0.1894	0.1905
	F Statistics		1.0951	1.2917	1.4731	1.5733

	Variable	Spot	F1	F2	F3	F4
Pre-Iraq War	Mean (%)	0.0150	0.0149	0.0154	0.0152	0.0151
	Std Dev	0.0252	0.0243	0.0208	0.0187	0.0175
	Skewness	-1.3887***	-1.5326***	-1.9440***	-1.7571***	-1.5000***
	Kurtosis	23.7929***	24.9110***	35.4246***	28.5700***	22.5287***
	J-B	87292***	95832***	193201***	126050***	78579***
	Beta	-0.1841	-0.2122	-0.1557	-0.1382	-0.1301
	Sharpe Ratio	-0.4513	-0.4482	-0.4607	-0.5164	-0.5583
	Treynor Index	0.0631	0.0525	0.0626	0.0714	0.0764
	Jensen Index	-0.0138	-0.0137	-0.0116	-0.0115	-0.0115
	F Statistics		1.0744	1.4733	1.8091	2.0805
Iraq War	Mean (%)	0.1135*	0.1138**	0.1154**	0.1177**	0.1191**
	Std Dev	0.0217	0.0207	0.0195	0.0185	0.0183
	Skewness	-0.3074***	-0.1354*	-0.0398	-0.0329	-0.1666**
	Kurtosis	3.7087***	1.0915***	0.5379***	0.4749***	2.4133***
	J-B	799***	72***	17***	13***	336***
	Beta	-0.0497	-0.0421	-0.0365	-0.0263	-0.0307
	Sharpe Ratio	12.4559	13.1195	14.0045	14.9236	15.2669
	Treynor Index	-5.5103	-6.5264	-7.5740	-10.6503	-9.2310
	Jensen Index	0.2767	0.2772	0.2783	0.2818	0.2852
	F Statistics		1.1047	1.2477	1.3774	1.4102

Note: ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively. The F statistic tests the equality of variances. Readers may refer to footnote 3 for the formulae of the Sharpe Ratio, Treynor Index, and Jensen Index, and for further information about these statistics.

Table 5: Results of LMW Test for the Portfolio of WTI Oil Spot and Futures

	100% Oil Futures		100% Oil Spot	
% of Oil Spot	P > F	F > P	P > S	S > P
10	0.5095	0.5504	0.4905	0.5165
20	0.5025	0.5974	0.4915	0.5085
30	0.4985	0.6254	0.4845	0.5485
40	0.5205	0.7273	0.4885	0.5524
50	0.5754	0.7353	0.4855	0.5604
60	0.6354	0.7333	0.4905	0.5844
70	0.6064	0.7602	0.4835	0.5984
80	0.5724	0.5674	0.4895	0.5754
90	0.5474	0.5055	0.4975	0.5574

Notes: The table reports the p-values of the LMW test for SSD of the portfolios (P) of oil spot and futures with oil spot (S) or futures (F) alone.[14] Readers may refer to Linton et al. (2005) for the LMW test statistics. The weight of oil spot in the portfolios is shown in the first column.

[14] We also conducted the test for FSD. As the conclusion drawn from FSD is the same as that from SSD, we do not report the FSD result.

Figure 1: WTI Crude Oil Spot Indices

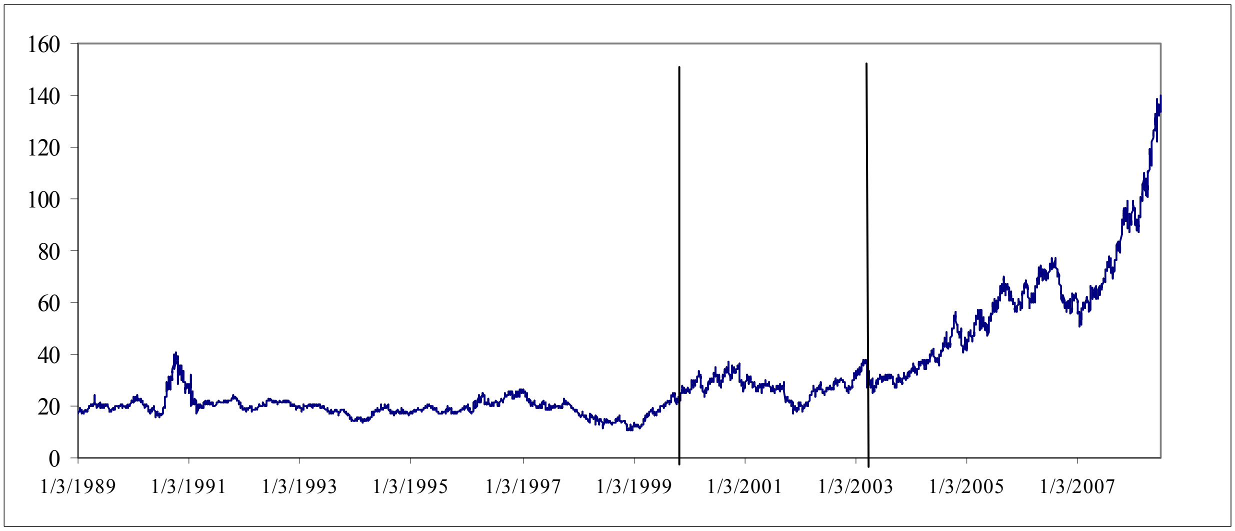
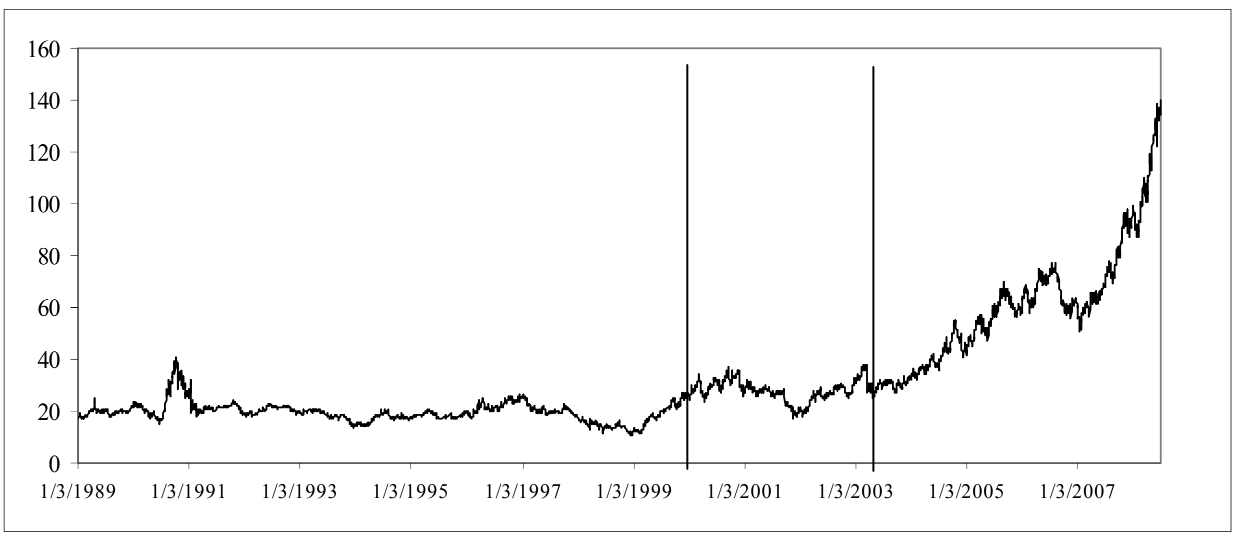


Figure 2: WTI Crude Oil Futures at one month maturity



Notes: These figures show the time series plots of oil spot and futures indices from January 1, 1989 to June 30, 2008. The first vertical line located at October 29, 1999 represents the cut-off point of the OPEC crisis, while the second vertical line located at March 20, 2003 represents the cut-off point of the Iraq War (see Section 2 for further details).

Appendix 1

Treynor index is one of the most widely used measures of portfolio performance. It is derived from Capital Asset Pricing Model (CAPM). Since the true value of beta is rarely known, the portfolio performance assessment must rely on a point estimate of this value to arrive at a point estimate of the Treynor index. Hence, the accuracy of point estimate of the Treynor index is not known. Hence, it is not easy to construct confidence interval or test statistic on Treynor index. Many papers that employed Treynor index to measure portfolio performance did not test the significant of it.

Previous work on developing a confidence interval on the Treynor index is limited. Jobson and Korkie (1981) method is only for the transformed difference of the Treynor index and says very little about constructing confidence intervals on the actual index. Moreover, they do not recommend the use of the Treynor index hypothesis tests. Cadsby (1986) found that Jobson and Korkie (1981) tests possess no power to distinguish between the null and certain plausible alternative hypotheses. Kryzanowski and Sim (1990) also developed an approach similar to the Jobson and Korkie using non-synchronous trading.

Morey and Morey (2000) presented a methodology to construct confidence intervals on Treynor index. The methodology is based upon the work of Roy and Potthoff (1953) and uses information from a simple regression equation to construct confidence intervals for the ratio of means from a correlated bivariate normal distribution.

The α% confidence interval of Treynor index is:

$$\frac{\bar{Y}\hat{\beta}_p \pm t\sqrt{\bar{Y}^2 s_{\hat{\beta}_p}^2 + \frac{s_Y^2}{n}\left(\hat{\beta}_p^2 - t^2 s_{\hat{\beta}_p}^2\right)}}{\hat{\beta}_p^2 - t^2 s_{\hat{\beta}_p}^2}$$

where $\bar{Y}$ is mean of $\left(r_t - r_f\right)$, $t = t_{n-1,\alpha/2}$, s_Y^2 is variance of $\left(r_t - r_f\right)$, $\hat{\beta}_p$ is the estimated slope of CAPM regression. If the confidence interval cover zero, then Treynor index is not significant different from zero. If β_p is not statistically different from zero, this formula cannot be used.

On the other hand, test statistic of Jensen index is just the t-statistic of α = 0 from the CAPM. It is wisely used by many empirically papers in the literature for example Cumby and Glen (1990), Abdullah et al. (2007).

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