COST OF CARRY ON STEROIDS: APPLICATION TO OIL FUTURES PRICING

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ABSTRACT

This paper develops an empirical cost of carry model with exogenously conditioned convenience yield. The approach is implemented using monthly prices of all futures contracts traded at the New York Mercantile Exchange between 1985 and 2006. Tests indicate that the model fits the data extremely well, much better than the unconditional model. Though the paper concentrates on oil, the approach can be used for any other commodity with well-developed futures markets.

JEL: F3; G1; N2

Keywords: Multifactor Models; Futures Pricing; Cost of Carry

INTRODUCTION

Influential empirical results on CAPM find that conditioning dramatically improves the performance of the simple CAPM (see Jagannathan and Wang, 1996; or Lettau and Ludvigson, 2001). Our paper applies the well-established process of "conditioning" in asset pricing theory to the cost of carry model to provide a novel approach to price commodity futures. Rather than implying endogenous pricing drift parameters from historical spot and futures price series, we condition the time-varying convenience yield with oil exporters and importers macro political, financial and economic factors. We test this stochastic convenience yield approach on the pricing of light crude oil futures. Our findings suggest that "conditioned spot prices" account for most futures price change behaviors not explained for under the unconditional cost of carry model. Further analysis of the residuals suggests that oil price behaviors might at times deviate from fundamentals.

The paper is organized as follows. Section 2 reviews the literatures on futures pricing. Section 3 contrasts the unconditional and our proposed conditional cost of carry model. Section 4 provides descriptive statistics on the data used in this study. Section 5 describes our testing of the conditional cost of carry model approach and discusses the implication of the residuals characteristics of the conditional model. Section 6 summarizes and concludes our paper.

LITERATURE REVIEW

Given the strategic and economic significance of oil pricing in financial markets, the finance literature is replete with studies involving oil. Several studies have provided the empirical evidence on the cost of carry model in various futures markets: Frenkel and Levich (1977) and Branson (1979) find no opportunities for arbitrage in currency futures markets after controlling for transactions costs while similar results are found by Rendleman and Carabini (1979) in the Treasury Bill futures market and Cornell (1985) in the SP500 futures market. On the other hand, Klemkosfy and Lasser (1985) fail to find support for the cost of carry model in the Treasury Bond futures market; Elton, Gruber and Rentzler (1985) reject the model for the Treasury Bill futures market – after controlling for transactions costs, they find the existence of abnormally high profit potentials in the interest rate futures market, suggesting the non-constancy of the carry costs. French (1983) compares forwards and futures prices in silver and copper commodity futures markets and finds a hedging premium. His results imply that futures prices are biased predictors of the future spot prices and that the cost of carry consists of elements beyond the risk-free rate of interest. Analyzing consumption commodity futures markets for corn, soybean and wheat, Chang (1985) finds similar results, i.e., that there is a hedging premium between the forwards and futures prices in these markets, implying that the cost of carry is not a constant function of the risk-free rate. Hansen and Rodrick (1980), Fama (1984), Huang and Chieng (1986) also find evidence of a non-constant hedging.

When applying the cost of carry model to commodity futures, Brennan (1986) introduces the concept of a convenience yield – a yield earned by the holder of the physical commodity in the present and a yield which cannot be earned by holding the commodity futures contract. While the only source of uncertainty in Black's cost-of-carry model was the underlying spot price of the asset in question, once the convenience yield was introduced for modeling commodity futures, the case was established for a non-constant convenience yield. Gibson and Schwartz (1989, 1990) show that in the case of crude oil futures, accurate pricing models can only be developed by allowing for stochastic convenience yields. Further, many firms' precautionary demand for storage is considered to be the main driver of the convenience yield and unanticipated shifts in the demand for immediacy could be the source of the random variations in the convenience yield.

Litzenberger and Rabinowitz (1995) also build the case for uncertainty in the convenience yield. Modeling oil wells as call options, they explain the circumstances of both strong and weak backwardation by introducing uncertainty into the cost-of-carry framework. Schwartz (1997) and Miltersen and Schwartz (1998) both present models for pricing commodity futures allowing for stochastic convenience yields and interest rates.

Hilliard and Reis (1998) develop a model of valuing commodity futures and options allowing for stochastic convenience yields as well as interest rates and jumps in the underlying spot prices. They evaluate one-factor, two-factor and three-factor models for futures and options and find that when the convenience yield is significantly above its long term mean values, the two-factor model performs better than the one-factor model.

Inspired by Schwartz's 1997 presidential address to the finance community of the American Finance Association, Casassus and Collin-Dufresne (2005) develop a three-factor model of futures spot prices, interest rates and convenience yields for commodity futures. Their model allows for a time-varying risk premia and the convenience yield is a function of both the interest rates and the underlying commodity's spot prices – their results for crude oil support the mean-reversion of convenience yields as they are linked to the underlying spot prices.

Hamilton (1983), Gilbert and Mork (1984) and Mork, Olsen and Mysen (1984) establish the significance of including macroeconomic variables in the study of oil pricing. Hamilton (1983) shows that oil price rises cause declines in real GDP while Gilbert and Mork (1984) examine the policy implications of the impact on financial markets and prices of a disruption in oil supplies.

Mork, Olsen and Mysen (1984) also confirm the negative relationship between oil prices and real GDP growth rates. Recognizing the role of macroeconomic variables, Huang, Masulis and Stoll (1996) examine the impact of oil prices on aggregate stock markets but fail to find a relationship in the 1980s. Switzer and El-Khoury (2007) look at the impact of periods of extreme volatility in underlying spot prices of oil such as during the periods of the Gulf War and the introduction of the new Iraqi government. Both futures and spot prices exhibit asymmetric volatility under such extreme conditions suggesting that future studies should account for such factors. The present study continues to allow for a non-constant convenience yield while making it conditional on relevant macroeconomic variables.

METHODOLOGY

One of the basic primes of the cost of carry models is that the only cost involved in pricing futures contracts is the financing cost. Light crude oil, however, is a commodity that differs from other commodities as it needs storage and is intended for consumption. It has spot prices that vary regionally, its consumption and production are highly variable, and it has significant storage costs. Crude has a high consumption relative to its inventory (as compared to investment futures such as financials or precious metals — gold, silver, platinum); it has little collateral value for borrowing and the risk of supply disruption is extremely high.

More importantly, because crude oil is a consumption commodity, even in the case a spot-futures arbitrage opportunity presents itself, a market participant cannot afford to sell his/her inventory to go long on futures contracts. Further, suppliers of crude may need to maintain some inventory to meet instantaneous increases in demand for the commodity. On the other hand, producers, distributors and industrial consumers of crude oil must hold inventory to fulfill their contracts, keep their factories running, avoid law suits and stay in business. All of these factors weaken the forces of arbitrage for maintaining efficient prices and force futures price to periodically be in backwardation—i.e., futures prices trail spot prices compounded at a carry premium (the sum of financing, storage, and transportation costs). In such cases, a critical equilibrium relationship depends on the "so-called" convenience yield — a premium required by speculators to compensate for a price risk that hedgers are willing to nullify. This "non-monetary cost" stems from the impossibility to operate reverse cash and carry arbitrage since crude is difficult to borrow and is used for consumption rather than investment purposes. There is a benefit to holding crude if there are shortage expectations. Thus, the convenience yield represents the return from holding crude now as opposed to later. The value of a convenience yield is time-varying and reflects expectations of changes in the demand and supply for crude — i.e., if the probability of shortages increases (decreases), the convenience yield increases (decreases).

In sum, any positive costs associated with storing or holding the asset in a cash and carry arbitrage will increase the non-arbitrage futures price. However, there may be benefits to holding oil (increases in demand or shortages in supply) and the return from this benefit is the convenience yield. To determine a futures price in the case of consumption commodities, the stochastic factors influencing the behavior of the underlying asset must be taken into consideration. For instance, oil futures prices are extremely sensitive to changes in convenience yields. In an expectations framework, one should recognize that the cost of carry is non-constant reflecting changes in demand and supply conditions for the underlying asset market — i.e., economic, financial, and political risk changes among countries that consume and produce the commodity. If conditioned by macro variables, spot prices are more likely to explain futures price changes in response to changes in market conditions.

According to the cost of carry model, futures prices should equal their cost of carry value, i.e.,

$$F_{T-t} = E(S_{T-t} | I_t) = S_t e^{C_t (T-t)} \qquad (1)$$

Where $F_{T\text{-}t}$ is the futures price at time t with a maturity of T-t, $E(S_{T\text{-}t})$ is T-t periods expected spot price at time t, C_t is the time-varying cost of carry yield. This pricing relation further implies the convergence of spot and futures prices at expiration.

This carry yield includes financing, storage, insurance, transportation, and convenience costs. The spot price and carry rates are both dependent on demand and supply forces affecting the commodity—in equilibrium, the futures price will be determined by the expectations of the fundamentals factors at the time of maturity of the futures contract. Thus, Equation (1) can be refined into:

$$F_{T-t} = S_t e^{(Rf_t + w_t - \gamma_t)(T-t)} \quad (2)$$

Where Rf_t is the risk free rate (or repo rate) at time t, w_t is the time varying storage cost yield, γ_t is the convenience yield, and w_t-γ_t is the net cost from holding the commodity at time t. For instance, if F_T-$S_o e^{RfT}$<0, we have a market in backwardation that can only be explained by a negative net cost from holding the commodity "w_t-γ_t" since the equilibrium requires that F_T-$S_o e^{(Rft+wt-\gamma t)T}$=0. In this case one can suspect supply disruption and/or demand increase for that commodity (if there is a shortage for the commodity, the spot has to increase relative to the futures price). Alternatively, if there is no concern of shortage for the commodity, the net cost of holding the commodity is positive and the market is in contango. Thus, expectations about demand and supply for the commodity are of paramount importance to the pricing of futures—i.e., prices are determined jointly by the hedging and speculative trades of investors.

The stochastic nature of convenience yield differ dramatically across futures markets-- In investment futures, there is a negligible convenience yield; In agricultural and metal markets, there is a more substantial convenience yield that fluctuates over time. In energy futures, especially oil, convenience yield fluctuations are notoriously large. Not only does the variance of convenience yield shocks vary across markets, but so does the persistence of these shocks (see Bessembinder et al., 1995). For instance, convenience yield shocks in energy markets tend to be very transitory, whereas such shocks in metal markets tend to be persistent.

So, equation 2, in a discrete time setting, needs to incorporate an exogenously specified stochastic convenience yield. In the same, spirit as Schwartz (1997), we can write equation 2 in a econometric setting where the default-free interest rate, the convenience yield, and the spot prices are stochastic, i.e.,

$$F^d{}_{T-t} = \alpha + S^d{}_t e^{Rft} b + S^d{}_t e^{Rft} Z_{t-1} B + \varepsilon_t$$

$$\textit{with} \quad (3)$$

$$F^d{}_{T-t} = F_{T-t} - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$$

$$S^d{}_t = S_t - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$$

where Z_{t-1} are sets of financial, economic, and political factors affecting producers and suppliers of oil, the natural logarithm of "b+Z_{t-1}B" is the (time-varying) net convenience yield "w_t-γ_t" (b is a value, B is a vector and α should be zero under the cost of carry equilibrium).

Since futures and spot price series are not stationary, we detrend trading volume time series by regressing the series on a deterministic function of month and time. $F^d{}_{T-t}$ and $S^d{}_{T-t}$ are the detrended and deseasoned futures and spot series, d_i is a dummy variable for each month of the year, T is the trend component—i.e. number of the month from 03/86 (T=1) to 10/06 (T=259). ARMA lags are determined with AIC.

DATA

The data, extracted from DataStream, consists of monthly spot and futures prices for light sweet crude oil contracts listed and traded on NYMEX from March 1985 to September 2006. The futures contract is the nearby rolled-over oil futures contracts traded at the NYMEX. The sample consists of 259 observations.

Oil prices are sensitive to inflation, disruption of supply, disruption of consumption, cost of transportation, extraction, storage, storage insurance, etc. In practice, oil prices vary over time depending on changes in economic, financial and political forces (growth in real GDP, inflation, strength of the Dollar, reserves/inventories, political crises and price controls, wars and conflicts, regulatory changes, quotas, embargos, etc.) affecting oil exporters and importers. In the past, oil prices have followed a cycle, extending over several years and responding to changes in demand as well as OPEC and non-OPEC supply. Generally oil prices are subjected to wide price swings in times of shortage or oversupply.

In addition, spot and futures oil prices vary seasonally within a year. For example, during the summer prices tend to hike as the US is entering its driving and hurricane seasons. Towards the end of the year, demand of heating oil increases also leading to higher oil prices. Typical troughs occur at the end of the hurricane season (September and October) and the beginning of spring when oil consumption is usually at its lowest annual level.

As mentioned in the methodology section, we orthogonolize spot and futures prices for trends and seasonal patterns using an ARMA(p,q) process adjusted with time and month effects. Table 1 reports the descriptive statistics for oil, spot, implied carry yield, and implied net convenience yield series. For instance, level prices statistics are similar between spot and futures. In addition, as evidenced by the ADF and KPSS tests, series are not stationary. For the adjusted series, spot and futures adjusted prices also show similar descriptive statistics and the series are found stationary. In addition, none of the demeaned and detrended series exhibit any autocorrelation. Carry and convenience yields do not show any autocorrelation either, but are, on average, negative, possibly implying the dominance of investment over consumption motives in oil futures trading.

Table 1: Descriptive Statistics (1985-2006, monthly data)

	Futures Prices		Spot Prices		Carry Yield Components	
	Level	Adjusted Level	Level	Adjusted Level	Carry Yield	Net Convenience Yield
Mean	25.59	0.00	25.61	0.00	-0.34%	-0.72%
Median	20.62	0.08	20.83	-0.02	0.28%	-0.12%
Maximum	74.40	12.00	74.41	7.15	15.94%	15.34%
Minimum	10.42	-6.88	11.28	-7.49	-19.76%	-20.32%
Std. Dev.	13.04	2.49	12.81	2.05	4.84%	4.86%
Skewness	2.05	0.23	2.02	0.18	-0.62	-0.64
Kurtosis	6.89	5.54	6.79	5.06	5.01	5.02
JB-Stat.	345.58***	71.84***	331.90***	47.23***	60.14***	61.48***
Obs.	259	259	259	259	259	259
ADF	-0.354	-15.881***	0.003	-16.066***	-14.609***	-14.490***
KPSS	1.053***	0.114	1.053***	0.108	0.289	0.381
Q1		0.02		0.25	2.15	2.55
Q6		4.14		9.86	10.18	11.07*
Q12		19.84*		24.37**	13.04	14.34

"Adjusted Level" refer to detrended and deseasoned futures and spot series. Series are constructed using the following ARMA (p,q) processes: $F^d{}_{T-t} = F_{T-t} - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$, $S^d{}_t = S_t - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$ Where, F^d_{T-t} and S^d_{T-t} are the detrended and deseasoned futures and spot series; F_{T-t} is the futures price at time t with a maturity of T-t, S_t is the spot price at time t; d_i is a dummy variable for each month of the year, T is the trend component—i.e. number of the month from 03/86 (T=1) to 10/06 (T=259). ARMA lags are determined with AIC. For any given month, the carry yield is defined by the logarithm of the ratio the futures price to the spot price, and the net convenience yield is the carry yield minus the the t-bill rate Critical Values for ADF (Ho: series is non-stationary) and KPSS (Ho: series is stationary) tests are 0.739 (1% level), -2.873 and 0.463 (5% level), and -2.573 and 0.347 (10% level). Q(p) is the Ljung-Box Q statistics on the first p lags of the sample autocorrelation function of the series, distributed as $\chi^2(p)$.

Like the prices of every other risky asset, oil futures prices include risk premiums to reflect the possibility that spot prices at the time of delivery may be higher or lower than the contracted price. We proxy political, financial, and economic risk premiums using risk ratings from the Country Risk Guide (ICRG) databank. We retrieve all composite, political, economic, and financial risk ratings for the countries exporting and importing 99 percent of the world oil—Top exporters are Saudi Arabia, Russia, Iran, Mexico, Kuwait, Nigeria, Norway, UAE, Venezuela, Algeria, Libya, and Qatar, in that order; top importers are USA, China, India, Canada, Brazil, France, Mexico, Italy and UK, in that order.

ICRG assesses a country risk based on three dimensions – political, economic and financial. Each dimension is measured using several factors. The political risk dimension is measured using twelve factors and the economics and financial risk dimensions are measured using five factors each. The ICRG scale for each factor is calibrated such that a high score indicates low risk and a low score indicates high risk. Finally, the ICRG system brings the political, economic and financial risk scores of a country together to compute a composite risk score for the country. This composite risk score is based on equally weighting of the political, economic and financial risk scores. Girard, and Sinha (2008) suggest that (i) risk score includes information that cannot be aggregated in a composite measure, and (ii) some risk factors have a greater bearing on business or investments than others. Thus, for a composite risk rating to be useful for an analysis of the kind we contemplate, the factors should be differentially weighted to allow for greater weight for those factors that have a greater bearing on business. Since this is not the case with the ICRG composite risk rating, we use the twenty-two primary ICRG risk factors (twelve political, and five each economic and financial) in preference to the ICRG composite measures.

Table 2: Factor Analysis on Percentage Change in Country Risk for Importers

	Factors (Top Oil Importers) USA, China, India, Canada, Brazil, France, Mexico, Italy and UK								
	1	2	3	4	5	6	7	8	9
Eigenvalue	3.61	2.25	1.24	1.20	1.18	1.14	1.12	1.11	1.09
% of Variance	17.17	10.73	5.88	5.73	5.64	5.41	5.35	5.27	5.20
Cumulative %	17.17	27.91	33.79	39.52	45.15	50.56	55.92	61.19	66.39
Current Account to GDP (E)	0.93	-0.05	-0.03	-0.05	0.01	0.03	0.06	0.02	-0.01
Investment profile (P)	0.83	0.03	0.00	-0.01	-0.10	0.05	0.17	0.01	-0.05
Budget balance (E)	0.80	-0.03	0.11	-0.02	-0.05	0.05	0.12	0.08	0.19
GDP per Population (E)	0.77	0.00	-0.08	-0.01	0.06	0.00	-0.13	0.04	-0.08
Real growth in GDP (E)	0.76	0.04	-0.03	-0.01	-0.02	-0.01	-0.04	-0.07	-0.16
Socioeconomic Conditions (P)	0.48	0.26	0.10	0.07	0.35	-0.17	-0.05	-0.07	0.15
Ethnic tensions (P)	-0.02	0.84	0.01	-0.12	-0.03	-0.01	-0.14	0.00	0.01
Religion Tensions (P)	0.01	0.78	0.16	-0.04	0.01	-0.09	0.14	0.13	0.02
Internal Conflicts (P)	0.04	0.73	-0.06	0.06	0.03	0.09	0.30	-0.02	-0.06
Law and Order (P)	0.01	0.03	0.77	-0.01	0.06	0.06	-0.05	0.21	0.00
Exchange Rate stability (F)	-0.02	0.06	0.72	0.13	-0.02	-0.02	0.05	-0.22	-0.06
Corruption (P)	0.03	0.08	0.15	0.80	-0.05	0.10	0.08	-0.04	0.05
Military in the Politics (P)	0.11	0.29	0.03	-0.61	0.05	0.16	0.09	-0.09	0.17
Bureaucratic Quality (P)	0.06	-0.02	-0.02	0.08	-0.79	0.07	0.05	-0.05	0.13
Government Stability (P)	0.04	-0.31	0.08	-0.08	0.48	0.48	0.22	-0.08	0.17
International liquidity (F)	-0.01	0.07	-0.06	0.04	0.17	-0.68	-0.06	-0.26	0.13
Democratic Accountability (P)	0.03	0.29	-0.05	0.12	0.11	0.59	-0.33	-0.34	0.09
External Conflicts (P)	0.09	0.21	0.00	0.03	-0.01	0.00	0.86	-0.05	-0.01
Inflation (E)	0.04	0.10	0.00	0.04	0.04	0.08	-0.05	0.86	0.04
Foreign Debt (F)	0.06	0.03	-0.03	0.20	0.22	0.06	0.04	0.06	-0.77
Current account/net export (F)	-0.04	0.02	-0.20	0.28	0.31	0.03	0.04	0.19	0.54

We retrieve from the International Country Risk Guide databank (ICRG) all composite, political, economic, and financial risk ratings for the countries consuming 99 percent of the world oil—USA, China, India, Canada, Brazil, France, Mexico, Italy and UK, in that order. We use the weighted average risk ratings among consumers—the weight is determine by the percentage contribution of one country to the world total consumption of oil (since our consumption data are annual, weights are changed on an annual basis). Then, the weighted average risk ratings are transformed into a percentage change in risk ratings. The factor Analysis is performed using the percentage change in consumers weighted average risk ratings.

Most likely, some risk variables are highly correlated with each other, which make their simultaneous use redundant. To eliminate this problem of endogenity, we use a Principal Component Analysis (PCA) to create a grouping or factor that captures the essence of these variables. Tables 2 and 3 present the results from the factor analysis. The Kaiser-Meyer-Olkin test (KMO) value for the sample is very high (0.778) and Barlett test of sphericity is significant at the 1% level, indicating that the factor analysis is an appropriate technique for our data. The number of common factors is found using a VARIMAX rotation.

We find 9 newly extracted factors for oil importers that are numbered from 1 to 9 (panel A), and 6 factors for oil exporters numbered from 1 to 6 (panel B). The eigenvalues represent the proportion of total variance in all the variables that is accounted for by that factor. To decide the number of factors to retain, we use the Kaiser criterion which consists in dropping the eigenvalues less than one—i.e., unless a factor extracts at least as much as the equivalent of one original variable, we drop it. The "% of variance" represents values expressed as a percentage of the total. For instance, factor 1 for "oil consumers" accounts for 17.17 percent of the variance, factor 2 for 10.73 percent, and so on. The "Cumulated %" contains the cumulative variance extracted and shows that the six dominant factors whose eigenvalues are more than one, sum up to 66.39 % of the total variance for oil importers and 67.65% of the total variance for oil exporters.

We also show the loading of each risk score variable within each factor. Interpretation and naming of the factors are not straightforward as they depend on the particular combination of observed variables that correlate highly with each factor. To minimize the subjective nature of the PCA, we only consider individual risk score loadings with "good" correlations. Comrey and Lee (1992) define a "good" correlation for a loading greater than 0.5 (or smaller than -0.5) — i.e., 25 percent overlapping variance. Each factor's composite score is determined by taking into account the risk scores that load highly on it. Accordingly, each factor's score is computed using a summated scale methodology.

Table 3: Factor Analysis on Percentage Change in Country Risk for Exporters

	Factors (Top oil exporters) Saudi Arabia, Russia, Iran, Mexico, Kuwait, Nigeria, Norway, UAE, Venezuela, Algeria, Libya, and Qatar					
	1	2	3	4	5	6
Eigenvalue	6.25	1.91	1.88	1.50	1.40	1.27
% of Variance	29.78	9.10	8.94	7.14	6.64	6.06
Cumulative %	29.78	38.88	47.81	54.95	61.59	67.65
Current Account to GDP (E)	-0.89	0.25	-0.03	0.13	0.05	0.07
Investment profile (P)	0.87	0.08	0.08	0.03	-0.07	0.18
Budget balance (E)	-0.84	0.28	0.03	0.08	0.07	0.06
GDP per Population (E)	0.80	0.33	0.06	-0.02	0.04	0.03
Real growth in GDP (E)	-0.80	0.23	0.18	0.03	0.06	0.10
Socioeconomic Conditions (P)	-0.74	0.27	0.11	0.28	0.02	0.19
Ethnic tensions (P)	0.73	-0.12	0.07	-0.21	-0.05	0.20
Religion Tensions (P)	0.71	0.44	0.09	-0.09	-0.07	-0.01
Internal Conflicts (P)	0.67	-0.07	0.03	0.07	0.05	0.06
Law and Order (P)	-0.42	0.75	-0.03	0.04	0.08	-0.10
Exchange Rate stability (F)	-0.09	0.72	0.03	0.03	0.00	0.05
Corruption (P)	-0.17	-0.13	0.75	-0.05	-0.15	-0.19
Military in the Politics (P)	-0.18	0.02	0.66	0.36	0.00	0.06
Bureaucratic Quality (P)	0.27	0.18	0.60	-0.18	0.23	0.11
Government Stability (P)	0.46	0.13	0.55	0.22	-0.09	0.24
International liquidity (F)	0.05	0.07	0.28	0.75	0.05	0.01
Democratic Accountability (P)	-0.27	-0.02	-0.16	0.70	-0.04	-0.02
External Conflicts (P)	-0.08	-0.06	-0.10	-0.09	0.80	-0.04
Inflation (E)	-0.06	0.11	0.08	0.10	0.79	0.03
Foreign Debt (F)	-0.11	-0.14	-0.07	-0.09	-0.05	0.83
Current account/net export (F)	0.26	0.36	0.14	0.18	0.08	0.57

We retrieve from the International Country Risk Guide databank (ICRG) all composite, political, economic, and financial risk ratings for the countries producing 99 percent of the world oil—Saudi Arabia, Russia, Iran, Mexico, Kuwait, Nigeria, Norway, UAE, Venezuela, Algeria, Libya, and Qatar, in that order. We use the weighted average risk ratings among producers and consumers—the weight is determine by the percentage contribution of one country to the world total consumption and production of oil (since our production data are annual, weights are changed on an annual basis). Then, the weighted average risk ratings are transformed into a percentage change in risk ratings. The factor Analysis is performed using the percentage change in producers weighted average risk ratings.

RESULTS

We use equation (3) to identify the significant factors that explain futures. We compare results of two models: Model (1) uses the unconditional cost of carry model and, model (2) uses the 17 factors constructed with the PCA to condition the net convenience yield. In Table 4, we report the coefficient (Coef), the standardized coefficient (SCoef), the absolute value of the standardized coefficient or "standard shock" (Std shock), the percentage of the standard shock as compared to the shocks for all independent variables (%Std shock), and the t-statistics (t-Stat). Under the null hypothesis of efficient markets (risk neutrality and rational expectations), the regression residuals will exhibit serial correlation. In order to obtain consistent estimates of the standard errors, necessary to conduct proper statistical inference, we calculate heteroskedasticity and serial correlation robust standard errors. We first turn our attention to the results of the mean equations of models 1 and 2. Table 4 reveals that spot prices are significantly related to futures prices. Indeed, slope coefficients are near unity for each model, and the models are well specified since the constant is not statistically significant. Thus, there is a natural drift up in the price change, even after accounting for other factors.

Table 4: Tests on Unconditional and Conditional Cost of Carry models (1985-2006)

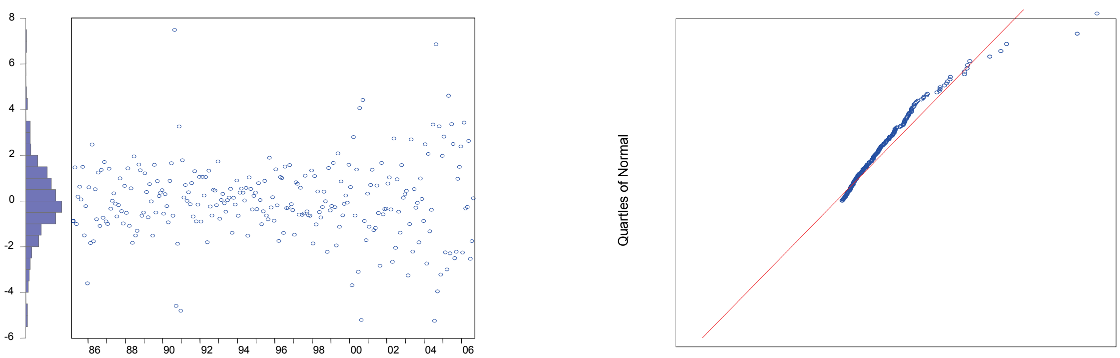
	Model 1 (Adj.R^2=0.43)					Model 2 (Adj.R^2=0.69)				
	Coef	SCoef	Std shock	% Std shock	t-Stat	Coef	SCoef	Std shock	% Std shock	t-Stat
(Constant)	0.001				0.009	-0.01				-0.13
$S^d e^{Rf}$	0.898	0.72	**0.72**	**100%**	12.909***	0.92	0.75	**0.75**	**50.5%**	15.83***
$S^d e^{Rf}$ x PE										
$S^d e^{Rf}$ x PF										
$S^d e^{Rf}$ x PP										
Std shock from consumers risk ratings										
$S^d e^{Rf}$ x PF1						-9.49	-0.09	0.09	6.4%	-2.08**
$S^d e^{Rf}$ x PF2						-10.31	-0.10	0.10	6.9%	-3.05***
$S^d e^{Rf}$ x PF3						-5.91	-0.06	0.06	4.0%	-1.89*
$S^d e^{Rf}$ x PF4						-8.03	-0.08	0.08	5.4%	-2.25**
$S^d e^{Rf}$ x PF5						1.44	0.01	0.01	1.0%	1.13
$S^d e^{Rf}$ x PF6						-5.30	-0.05	0.05	3.5%	-1.79*
Std shock from producers risk factors								**0.40**	**27.1%**	
$S^d e^{Rf}$ x CF1						-5.20	-0.05	0.05	3.5%	-1.99**
$S^d e^{Rf}$ x CF2						-7.56	-0.08	0.08	5.1%	-2.68***
$S^d e^{Rf}$ x CF3						-4.03	-0.04	0.04	2.7%	-1.72*
$S^d e^{Rf}$ x CF4						-1.76	-0.02	0.02	1.2%	-0.60
$S^d e^{Rf}$ x CF5						1.87	0.02	0.02	1.3%	1.05
$S^d e^{Rf}$ x CF6						1.99	0.02	0.02	1.3%	1.23
$S^d e^{Rf}$ x CF7						-2.10	-0.02	0.02	1.4%	-1.27
$S^d e^{Rf}$ x CF8						-4.00	-0.04	0.04	2.7%	-1.56
$S^d e^{Rf}$ x CF9						4.99	0.05	0.05	3.3%	1.63
Std shock from consumers risk factors								**0.33**	**22.4%**	
Std shock from all independent variables			**0.72**	**100%**				**1.90**	**100%**	

Model 1: $F^d_{T-t} = \alpha + S^d_t e^{Rft} B^* + \varepsilon_t$ and Model 2: $F^d{}_{T-t} = \alpha + S^d{}_t e^{Rft} b^* + S^d{}_t e^{Rft} Z^f{}_{t-1} B^* + \varepsilon^*_t$. Where $R_{f,t}$ is the monthly risk-free rate (T-bill rate), $Z^c{}_{t-1}$ is a vector the 6 lagged composite ratings for producers and consumers of oil, $Z^f{}_{t-1}$ is a vector of 15 lagged rating factors for producers and consumers of oil, ln(B^*) is the net convenience yield, F^d_{T-t} and S^d_t are the detrended and deseasoned front month futures and spot prices, i.e., $F^d{}_{T-t} = F_{T-t} - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$ and $S^d{}_t = S_t - [\sum_{i=1}^{12} \beta^1{}_i d_i + \beta^2 T + \beta^3 T^2 + ARMA(p,q)]$

In addition, PCA risks (model 2) have significant bearings on futures prices. In fact, Model 2 has the highest r-squared and includes information beyond model 1. More specifically, model 2 shows that a 1 standard deviation shock in the Spot price leads to leads to 0.75 standard deviation shock on futures prices. Furthermore, a 1 standard deviation shock in each of the exporters' (importers) factors leads to a 0.40 (0.33) standard deviation shock on futures prices. Thus, oil futures-spot spreads tend to be more affected by supply surpluses or shortages than demand-related shock. In addition, supply-related shocks are statistically more significant than demand-related shocks. This finding obviously warrants the use of a (news) conditioned pricing model rather than the unconditional "cost of carry model."

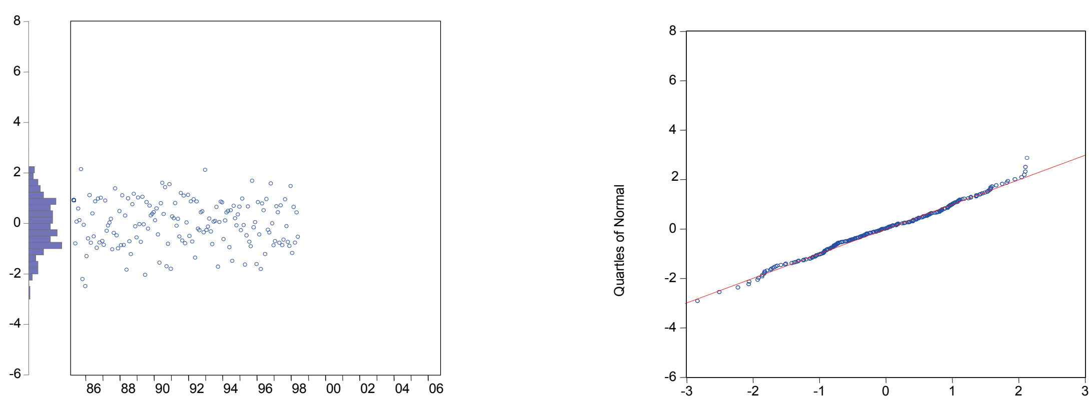
Although, the purpose of this paper is not to forecast oil prices (we have too few monthly data point to provide meaningful out-of-the-sample forecasts), our in-the-sample results provides interesting information regarding the mispricing of crude oil futures. That is, the conditional models with stochastic volatility better explain the mispricing of futures oil prices. Figures 1 and 2 show a plot of the residuals, the inherent histogram and a quantile-quantile plot (actual versus normal) for each of the model. Notice that, as compared to the residuals of model 2, the residuals of model 1 overshoot and undershoot the 2 standard error mark numerous times, especially after 2000. Again, it demonstrates that most of extreme futures price movements can be explained by fundamental political, financial and economic shocks. Finally, quantile-quantile plot shows that the unconditional model tend to overestimate small price increase and large price decrease, and underestimate small price decrease and large price increase. On the other hand, model 2 does a good job explaining small and medium size price movements, but tend to underestimate large price decrease and overestimate large price increase.

Figure 1: Residuals Plot, histogram and theoretical Quantile-Quantile Plot for Model 1



This figure shows the residual plot, histogram and theoretical Q-Q Pot for Model 1

Figure 2: Residuals Plot, Histogram and Theoretical Quantile-Quantile Plot for Model 2



This figure shows the residual plot, histogram and theoretical Q-Q Pot for Model 2

CONCLUSION

Several studies have investigated the efficacy of the cost of carry models in pricing futures contracts. While Frenkel and Levich (1977) and Branson (1979) study currency futures, Rendleman and Carabini (1979), and Elton, Gruber and Rentzler (1985) investigates Treasury bill futures. Klemkosfy and Lasser (1985) on the other hand looks at Treasury Bond futures while Cornell (1985) investigates SP500 futures.

French (1983) investigates the cost of carry framework using forward and futures prices of silver and copper. Although most of these studies do not adjust for convenience yield, Gibson and Schwartz (1989, 1990) show that models allowing for stochastic convenience yields may result in greater accuracy of pricing futures contracts especially of crude oil. Given Gibson and Schwartz (1989, 1990), Litzenberger and Rabinowitz (1995), Schwartz (1997), Miltersen and Schwartz (1998), and Hilliard and Reis (1998) findings on stochastic convenience yields, and Hamilton (1983), Gilbert and Mork (1984) and Mork, Olsen and Mysen (1984) findings about the importance of including macroeconomic variables in the study of oil pricing. We develop a cost of carry model for oil futures that assumes stochastic convenience yield crude oil and incorporates political, financial and economic risk shocks among producers and consumers of crude oil. Our results indicate that (1) a conditional model which incorporates the risk rating factors provides a better modeling framework than the unconditional framework. As a result, future research should attempt to further relax stochastic assumptions such as stochastic volatility to better fit the cost of carry model to reality.

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