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Modelling and Forecasting Oil Prices: The Role of Asymmetric Cycles

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Modelling and Forecasting Oil Prices: The Role of Asymmetric Cycles

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Abstract

We propose a new time series model aimed at forecasting crude oil prices. The proposed specification is an unobserved components model with an asymmetric cyclical component. The asymmetric cycle is defined as a sine-cosine wave where the frequency of the cycle depends on past oil price observations. We show that oil price forecasts improve significantly when this asymmetry is explicitly modelled.

Keywords: Oil price, forecasting, nonlinear time series analysis, asymmetric cycles.

JEL Classifications: C22, O13, C53.

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1 Introduction

Crude oil is the world's most actively traded commodity both in volume and in value. Until the creation of futures markets in mid 1980s, crude oil was largely sold by producers to consumers under long term contracts. Since then the oil market has become liberal and highly liquid in which price discovery has been concentrated around three marker crudes - WTI, Brent and Dubai. These markers are considered to be the reference for all oil traded worldwide.

Oil is traded in futures (WTI on NYMEX and Brent on ICE) and other derivatives markets mostly not to supply physical barrels but rather as a hedge to distribute risk.[1] As a result, trading in futures and derivatives markets by its very nature imply volatility in which strategies of traders vary based on fundamentals and perceptions on current and future market fundamentals. When the median average of WTI shifted from below $20 per barrel (between mid 1983 to end 1999) to over $32 per barrel (in 2000s), seeing as high as $75 in 2006 and 2007, concerns have been raised whether this was a temporary or a permanent change.

Analysts have no agreement on why oil prices surged in recent years and what the causes were behind it. Oil prices in the past years do not correspond to market fundamentals (supply and demand) any more since the formulae at which oil is sold by exporting countries generally reflect futures prices which do not move exclusively in response to physical oil supply and demand conditions. Moreover, it is argued that because of the polarized structure of the oil industry dominated by the influence of the upstream and downstream cartels or oligopolies, global oil prices do not always behave in accordance with conventional free supply and demand theory.[2] This has raised the question this time as to whether some sort of structural and/or cyclical factors could be the main drivers.

[1] The daily trading volume of front month West Texas Intermediate crude oil contract, which is the subject of this article, is for example, several times higher than spot crude oil sold in the world.

[2] See for instance Wood and Mokhatab (2006).

Structural factors include an upward shift in Asian oil demand, erosion of spare capacity in supply chain, OPEC behaviour, an increasing weight of institutional investors (such as hedge funds and pension funds) in trading activity, refining margins, depreciation of dollar against all major currencies and the break up of the strong relationship between U.S. crude stocks and oil prices, just to name a few. Cyclical factors correspond to traders reaction to and perceptions about current and future market fundamentals influenced by diverging statements and announcements made by OPEC and its members, geopolitical developments including civil unrest and crisis in major producing countries, fears of supply disruptions, attacks on oil facilities and infrastructure, extreme weather effects, economic forecasts, news, and rumors. Those factors cannot cause prices to move permanently in a direction opposed to market fundamentals but play an important role with regard to market expectations and perceptions.

The existence of commodity cycles has long been documented in the economic literature (see, e.g., Kondratieff, 1925; Dewey and Dakin, 1947). If these cycles are deemed to have any merit, projections into the short-term and long-term future on commodity prices can be made based upon the periodicity of the cyclical behaviour observed. Carson (2006) argues that commodity prices generally tend to be a very good barometer of the business cycle in that strong prices reflect robust economic growth, while soft prices reflect economic weakness – particularly among countries that are big commodity buyers. Additionally, commodity prices may be influenced by (potentially cyclical) monetary factors, a typical example being the dollar exchange rate, given that most commodity prices are denominated in dollars. It is expected therefore that movements in the exchange rate of major currencies against the dollar have an impact on dollar denominated commodity prices (see for instance Breitenfellner and Crespo Cuaresma, 2007, Mundell, 2002, Jumah and Kunst, 2001 or Deaton and Miller, 1995).

In analysing the properties of several commodity price series, Deaton and Laroque (1992) find a variety of statistical features such as non-normal skewness and leptokurtosis in returns, coupled with serial correlation, as evidence of non-linear dynamic price behaviour and non-normality in the price distribution. They mention the impossibility of the market as a whole to carry negative inventories as a cause of non-linear dynamic behaviour in the prices of storable commodities. Their results suggest that commodity price cycles are best modelled by nonlinear (asymmetric) models.

Besides the non-negativity of storage explaining supply-side asymmetry in oil prices, several recent studies have revealed responses of output to oil prices that are not log-linear. For example, Mork et al. (1994), Cuñado and Pérez de Gracia (2005), and Jimenez-Rodriguez and Sanchez (2004) have reported evidence of non-linearity, with oil price increases reducing real output growth for a number of other countries. These latter findings might indicate a theoretical possibility of supply-side asymmetry in oil prices being reinforced by demand-side factors.

In this paper we propose a simple time series model with asymmetric cyclical behaviour and compare it to linear symmetric alternatives in terms of its out-of-sample forecasting performance for crude oil prices. The specification is based on a univariate unobserved components model. While other similar studies (e.g., Reinhart and Wickham, 1994) tend to assume symmetric behaviour when modelling crude oil price time series, we follow generalized models in the spirit of Crespo Cuaresma (2003) by assuming asymmetric cyclical behaviour in crude oil prices around a reasonably general trend. Our results present evidence of better forecasting abilities for the nonlinear model when compared to a benchmark autoregressive model and to its symmetric counterpart. The improvements appear sizeable and statistically significant for relatively long forecasting horizons (one year or more).

The paper is organized as follows. Section two presents the unobserved components model with an asymmetric cycle which will be used in the forecasting exercise. Section three presents an empirical modelling and forecasting exercise aimed at assessing the evidence of asymmetry in the cyclical behaviour of oil prices. The potential improvements in out-of-sample forecasting are also explicitly evaluated. Section four concludes and sketches future paths of research.

2 Oil prices and asymmetric cycles: The unobserved components model

Time series of oil prices present very strong persistence, local trends over relatively long periods of time and apparent cyclical behaviour at higher frequencies. Figure 1 presents monthly data for the period January 1983- August 2007 for the front-month contract price of a West Texas Intermediate barrel (source: Energy Information Administration, U.S. Department of Energy),[3] which will be the series of interest for our analysis.

`[Insert Figure 1 about here]`

The strong persistence of the series mirrors itself in the fact that the null hypothesis of a unit root cannot be rejected at any sensible significance level when performing an Augmented Dickey-Fuller (ADF) test to the oil price data.[4] The data on percentage changes in the oil price (the first difference in the log of the data presented in Figure 1), in turn, is presented in Figure 2.

`[Insert Figure 2 about here]`

The distribution of the first-differenced data presents strong excess kurtosis and slightly negative skewness. The null hypothesis of normally distributed data can be rejected at all reasonable significance levels when using a Jarque-Bera test for Gaussianity of the distribution. In principle the deviation of normality can be taken as some preliminary evidence that nonlinear dynamic structures will be necessary in the specification of the model for oil prices.

We propose the use of a simple univariate unobserved components model in order

[3]The data are freely available at the webpage of the Energy Information Administration: http://eia.doe.gov.

[4]A similar qualitative conclusion is reached if a KPSS test (with stationarity as the null hypothesis) is used instead. Detailed results on the unit root tests are available from the authors upon request.

to jointly capture the stochastic trend and the cyclical behaviour of the oil price series. In particular, we propose a model including a stochastic trend (a general I(2) trend nesting the cases of a random walk and a linear deterministic trend) and a general asymmetric cyclical component which nests the case of a symmetric cycle as a special testable case. This class of models was proposed in Crespo Cuaresma (2003) to evaluate the existence of nonlinear cycles in macroeconomic time series.

We assume that the data generating process for oil prices can be decomposed multiplicatively into a trend, cyclical and irregular (white noise) component which are uncorrelated among each other, so that the log of oil prices (p_t) can be written as

$$p_t = \tau_t + \phi_t + \epsilon_t, \qquad \epsilon_t \sim \text{NID}(0, \sigma_\epsilon^2). \tag{1}$$

The trend component (τ_t) captures the low frequency component of the series and can be specified as a general second-order integrated process,

$$\tau_t = \tau_{t-1} + \beta_{t-1} + \upsilon_t, \qquad \upsilon_t \sim \text{NID}(0, \sigma_\upsilon^2), \tag{2}$$

$$\beta_t = \beta_{t-1} + \xi_t, \qquad \xi_t \sim \text{NID}(0, \sigma_\xi^2), \tag{3}$$

where υ_t and ξ_t are shocks which are assumed to be uncorrelated mutually and with the irregular component, ϵ_t. The special case of a random walk trend is nested in the specification given by (2) and (3) if σ_ξ^2=0 and σ_υ^2 >0, the smooth trend case appears for the case σ_ξ^2 >0 and σ_υ^2=0 and the trend component is a linear deterministic trend if σ_ξ^2=0 and σ_υ^2=0.

In the spirit of Harvey (1989), we will specify the cyclical component ϕ_t as a stochastic sine-cosine wave. We will however assume that the frequency of the cycle may depend on past realizations of the process, so that asymmetric cycles may arise. We hypothesize the existence of two regimes with different cyclical frequencies depending on some function of past values of p_t.[5] The specification we propose for ϕ_t is

[5]Obviously, other specifications of the cyclical component may also lead to asymmetric cycles. The one proposed in this paper has the advantage of being easy to estimate and interpret. The generalization to the existence of more than two regimes is straightforward.

therefore given by

$$\begin{aligned}
\phi_t &= \rho\left\{I(\{p_s\}_{s=1}^{t-1})\mathrm{cos}\lambda_1+[1-I(\{p_s\}_{s=1}^{t-1})]\mathrm{cos}\lambda_2\right\}\phi_{t-1}+ \\
&\quad +\rho\left\{I(\{p_s\}_{s=1}^{t-1})\mathrm{sin}\lambda_1+[1-I(\{p_s\}_{s=1}^{t-1})]\mathrm{sin}\lambda_2\right\}\phi^*_{t-1}+\omega_t, \qquad (4)\\
\phi^*_t &= \rho\left\{-I(\{p_s\}_{s=1}^{t-1})\mathrm{sin}\lambda_1-[1-I(\{p_s\}_{s=1}^{t-1})]\mathrm{sin}\lambda_2\right\}\phi_{t-1}+ \\
&\quad +\rho\left\{I(\{p_s\}_{s=1}^{t-1})\mathrm{cos}\lambda_1+[1-I(\{p_s\}_{s=1}^{t-1})]\mathrm{cos}\lambda_2\right\}\phi^*_{t-1}+\omega^*_t, \qquad (5)
\end{aligned}$$

where ϕ^*_t appears by construction, $\rho \in [0,1)$ is a damping factor, λ_1 and λ_2 are the frequencies of the cycle in the two possible regimes ($\lambda_1 \in [0,\pi]$, $\lambda_2 \in [0,\pi]$), ω_t and ω^*_t are iid normally distributed disturbances, mutually uncorrelated and with equal, fixed variance σ^2_ω, $I(\{y_\tau\}_{\tau=1}^{t-1})$ is an indicator function taking value one if a given function of the realized values, $f(\{y_\tau\}_{\tau=1}^{t-1})$ is positive and zero otherwise, that is,

$$I(\{p_s\}_{\tau=1}^{t-1}) = \begin{cases} 1 & \text{if } f(\{p_s\}_{s=1}^{t-1}) > 0, \\ 0 & \text{if } f(\{p_s\}_{s=1}^{t-1}) \leq 0. \end{cases}$$

If $\lambda_1 = \lambda_2$, the model boils down to the symmetric trend plus cycle model developed by Harvey (1985, 1989). Once the function $f(\cdot)$ has been specified, this is a testable hypothesis, so that the existence of asymmetric cycles can be verified statistically with the data at hand. In principle, the form of $f(\cdot)$ is left to the discretion of the scientist. One may assume for instance that the asymmetry in the cycle is triggered by whether oil prices increased or decreased in the last P periods or whether their growth rate was higher or lower than some exogenous value g. In these cases the functions $f(\cdot)$ would be given by $f(\{p_s\}_{s=1}^{t-1}) = p_{t-1} - p_{t-1-S}$ and $f(\{p_s\}_{s=1}^{t-1}) = p_{t-1} - p_{t-1-S} - g$, respectively.

Given the fact that in period t the realization of the $f(\cdot)$ function is known, the model is conditionally Gaussian and can be easily estimated using Kalman filtering methods. The details on the estimation of the model are found in Crespo Cuaresma (2003).

3 Empirical results: Modelling and forecasting oil prices using asymmetric cycles

The aim of this section is to evaluate if the explicit modelling of asymmetric cycles in oil prices can contribute to improvements in out-of-sample forecasts. We will use the sample ranging from January 1983 to December 1995 as the first in-sample period. Based on this sample, we estimate a simple autoregressive model in the first difference of the log of oil prices, an unobserved components model with symmetric cycles (that is, imposing $\lambda_1 = \lambda_2$ in the specification given by (4) and (5)) and an unobserved components model with the yearly growth rate of oil prices as threshold function f, that is, for monthly data, $f(\{p_s\}_{s=1}^{t-1}) = p_{t-1} - p_{t-13}$. With the estimated model, forecasts up to three years (36 months) ahead are obtained, and the forecasting error is calculated using the actual data.[6] A new observation (the one corresponding to January 1996) is added to the in-sample subsample, and the procedure is repeated. This is done until no out-of-sample observations are available (that is, until the observation corresponding to August 2007 is reached). At this stage two statistics evaluating the forecast accuracy of the point forecasts of the models being studied (Root Mean Square Forecasting Error, RMSFE, and the Direction of Change statistic, DOC) are computed by comparing the forecasts with the actually realized values. These statistics are defined as

$$\text{RMSFE}(k) = \sqrt{\sum_{j=0}^{N_k-1} \frac{[p^f_{t+j+k} - p_{t+j+k}]^2}{N_k}},$$

$$\text{DOC}(k) = \sum_{j=0}^{N_k-1} \frac{I[\text{sgn}(p^f_{t+j+k} - p_{t+j}) = \text{sgn}(p_{t+j+k} - p_{t+j})]}{N_k},$$

where $k = 1, \ldots, 12$ denotes the forecast step, N_k is the total number of k-steps ahead forecasts, $I[\cdot]$ is the Heavyside function, taking value one if the argument is true and zero otherwise, and p^f_t is the forecast value for the oil price.

[6] The lag length of the autoregressive model on first differences is chosen by minimizing the AIC over lag lengths ranging from one to twelve. The choice of lag length is repeated every time a new observation is added to the sample.

As an extra evaluation instrument, we test whether the differences in forecasting ability are significant across models using the Diebold-Mariano test (Diebold and Mariano, 1995). For a given forecasting horizon h, the Diebold-Mariano test statistic, S_1, is given by

$$S_1 = [\hat{V}(\bar{d})]^{-\frac{1}{2}}\bar{d},$$

where $\bar{d}$ is the average difference between the forecasting error (measured alternatively as RMFSE) of the models being compared and $\hat{V}(\bar{d})$ is an estimate of the asymptotic variance of $\bar{d}$, given by

$$\hat{V}(\bar{d}) = \frac{1}{n}\left[\hat{\gamma}_0 + 2\sum_{k=1}^{h-1}\hat{\gamma}_k\right],$$

where n is the number of forecasts at the forecasting horizon we are investigating, and $\hat{\gamma}_k$ is the sample autocovariance of the forecasting error difference. The asymptotic distribution of S_1 is standard normal.

We also evaluate the direction of change statistics by comparing the computed statistics for each model with the "toin coss" ($p = 0.5$) benchmark. We use a normal approximation for the binomial distribution, and obtain a test statistic using the Z score, which allows us to test the null hypothesis $p = 0.5$ against $p \neq 0.5$.

The estimation of the asymmetric model corresponding to the first in-sample period already presents significant evidence of deviations from symmetry in the estimated cycle. For the regime defined by $p_{t-1} - p_{t-13} > 0$ the estimate of the cyclical frequency is 0.27 (with a standard error of 0.05), and for the complementary regime, $p_{t-1} - p_{t-13} > 0$, the cyclical frequency is estimated to be 0.07 (with standard error 0.02). A Wald test strongly rejects the null of equality of cyclical frequencies across regimes (the test statistic equals 15.22, with a p-value smaller than 0.01).

Table 1 summarizes the results of the forecasting exercise in terms of RMSFE, and Table 2 presents the results of the direction of change statistics (DOC), defined as the proportion of times that the direction of change in the oil price variable was correctly forecast. In Table 1 the results of Diebold-Mariano tests (Diebold and

Mariano, 1995) for equality of forecast ability are also reported in the form of significance levels, and for the case of the DOC statistics in Table 2 also binomial tests for the proportions of correctly forecast directions being equal to 0.5 are reported. The asymmetric cycle model outperforms its symmetric rival at all forecasting horizons with regard to the RMSFE. Improvement over the autoregressive benchmark is observed for all forecasting horizons with the exception of 6-months ahead. The Diebold-Mariano test gives evidence that the simple autoregressive model improves forcasts significantly over the symmetric cycle model, but not over the assymetric alternative. As regards the direction of change statistics presented in Table 2, in six out of seven cases the unobserved components model with asymmetric cycles beat its rival models with regard to the proportion of times that the direction of change in the oil price variable was correctly forecast. Moreover, results of the binomial test for the proportions of correctly forecast directions being equal to 0.5, were significant at the 10 percent level in forecasts at horizons of 18 and 24 months, for which the asymmetric cycle models presents proportions higher than 50% .

The findings from the two tables reveal that the asymmetric model can be used to improve the accuracy of oil price forecasts. Exploiting the asymmetric characteristics of the cyclical behaviour of oil price data can thus be considered a fruitful avenue of research for understanding the dynamics of commodity prices.

4 Conclusions

Forecasting future oil prices is wrought with extreme difficulty. Not only must one take into account the structural market fundamentals, like supply and demand, but one must also consider and anticipate the cyclical non-fundamentals, like all other elements that may potentially affect expectations and perceptions. In this paper we attempt to counteract these complexities associated with modelling and forecasting oil prices, i.e., from practical urgency, by proposing a simple non-linear univariate time series specification. This model is able to accommodate asymmetric cyclical behaviour in a simple manner in an otherwise standard unobserved components model. Our findings present ample evidence that the nonlinear model is superior in terms of forecasting performance, when compared to its symmetric counterpart as well as a benchmark autoregressive model. Our results support the view of Wang et al. (2005) that a nonlinear approach produces a substantial improvement in the accuracy of oil price forecasts. We deduce that exploiting the asymmetric characteristics of the cyclical behaviour of oil price data can be considered a fruitful avenue of research for understanding the dynamics of commodity prices.

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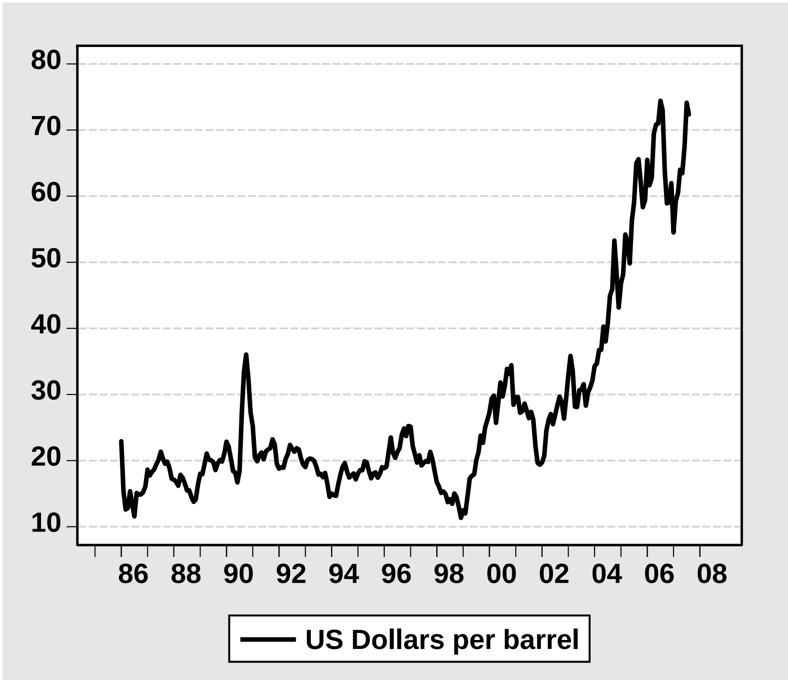

Figure 1: West Texas Intermediate: US dollar per barrel, monthly data (January 1983-August 2007)

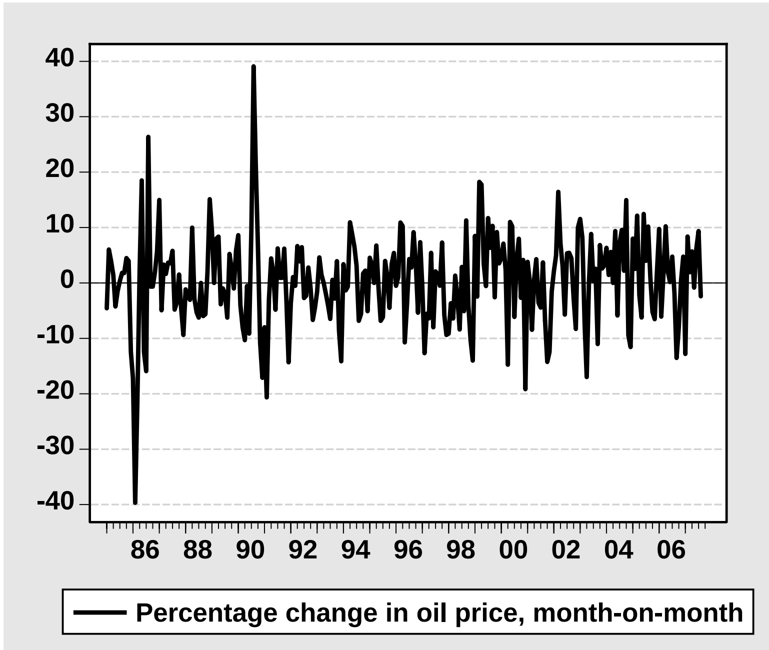

Figure 2: West Texas Intermediate: US dollar per barrel, percentage change month-on-month (January 1983-August 2007)

Steps ahead	UC model/AR model	UC model with AC/AR model	Obs.
1	1.16***	0.99	139
6	1.63***	1.05	134
12	1.64***	0.99	128
18	1.41**	0.94	122
24	1.22**	0.96	116
30	1.15*	0.99	110
36	1.12*	0.99	104

"UC model" refers to the unobserved components model with symmetric cycle, "UC model with AC" refers to the unobserved components model with asymmetric cycle. * (**) [***] stands for 10% (5%) [1%] significance using the Diebold-Mariano test.

Table 1: Forecasting results: RMSFE comparisons

Months ahead	AR model	UC model	UC model with AC	Obs.
1	0.47	0.42**	0.46	139
6	0.44*	0.44*	0.51	134
12	0.43*	0.50	0.52	128
18	0.48	0.50	0.56*	122
24	0.46	0.46	0.56*	116
30	0.44*	0.44*	0.53	110
36	0.37***	0.37***	0.43*	104

"UC model" refers to the unobserved components model with symmetric cycle, "UC model with AC" refers to the unobserved components model with asymmetric cycle. *(**)[***] stands for significantly different from 0.5 at the 10% (5%) [***] significance level.

Table 2: Forecasting results: Direction of change statistics

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