THE CYCLICALITY OF THE DEMAND FOR CRUDE OIL: EVIDENCE FROM THE OECD

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ABSTRACT

This paper analyses the cyclical relationship between the demand for oil and real output for the OECD, by employing the structural time series model developed by Harvey (1985, 1989). Using quarterly data for the period 1984:1 to 2010:4, a strong and positive cyclical relationship between the two variables is found, with the demand for crude oil being procyclically contemporaneous. This finding suggests that consuming countries cannot stockpile oil reserves to guard against the cyclical nature of demand, while producing countries will face weak and bearish oil markets during economic recessions, because oil consuming countries cannot smooth out their demand for oil on an intertemporal basis.

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***Keywords*:** Oil and the OECD; Cyclical Fluctuations; Structural Time Series Modelling

1. Introduction

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Since the end of World War II, there has been strong interest by practitioners and policymakers in the question of how the behaviour of the demand for crude oil affects economic activity. This is because almost all economic activity is based on the use of crude oil. Indeed, the use of crude oil provides around 40 per cent of the world's total energy needs, making it an important strategic commodity for many countries.

As an input in the production process, the behaviour of the demand for crude oil should reflect both the secular long-run and cyclical short-run movements of real output. While the secular long-run relationship between the demand for crude oil and real output is easily seen, the latent cyclical relationship is not, because it is not a simple matter to distinguish between the unobserved cyclical movements and other variations. The cyclical relationship, however, is very important for both the oil-exporting and oil-importing countries. It is important for the oil-exporting countries because the magnitude of the impact of an economic slowdown on the demand for, and the price of, crude oil will directly affect their export receipts earned from crude oil. On the other hand, the cyclical behaviour is important for oil-importing countries because it may have important implications for the effectiveness of stockpiling crude oil reserves, in an attempt to smooth out demand.

However, an important problem that faces practitioners who examine the cyclical relationship between the demand for crude oil and real output is measuring how much of an actual change in crude oil demand is due to cyclical factors. Practitioners normally overcome this problem by eliminating the time trend, either by taking the first difference or by fitting a time trend to the underlying time series. The cyclical component is then represented by either the percentage change in the series or by the difference between the total time series and the fitted time trend. These are clearly very crude methods, which may lead to measurement errors and, therefore, spurious results.

In this paper, the objective is to analyse the cyclical relationship between the demand for crude oil and real output, using quarterly data for the OECD, over the period 1984:1 to 2010:4. Unlike much of the *extant* literature, this study uses an alternative approach to decompose an observed time series into its unobserved components, using the structural time series model developed by Harvey (1985, 1989). This approach is considered to be superior to other trend and cyclical extraction methods, such as the Hodrick and Prescott (1980, 1997) filter, the Baxter and King (1997, 1999) bandpass filter, and the Christiano and Fitzgerald (1999, 2003) 'ideal' bandpass filter.

A recurring issue that arises when using the Hodrick and Prescott (1980, 1997) filter is the value assigned to the smoothing parameter, λ. It has been shown that the use of a standardised value for λ may distort the cyclical properties of the data by generating spurious cyclical correlations.[1] Similarly, the bandpass filter developed by Baxter and King (1997, 1999) is not without its problems. In particular, filtering in the time domain using moving averages involves the loss of a number of observations. On the other hand, setting a minimum moving average order of at least 12, irrespective of the number of observations, as Baxter and King (1997, 1999) suggest, will cause significant compression and high leakage of observations in the filtered series. Furthermore, Baxter and King (1997, 1999) argue that a good filter should not depend on the amount of data that is available, thereby neglecting any new information that becomes available when the number of observations increases. Clearly, as more observations become available, it is important to take this into account to improve the quality of the filtered series.[2]

Finally, the 'ideal' bandpass filter developed by Christiano and Fitzgerald (1999, 2003) also has a number of severe deficiencies. Along with the standard compression and

[1] For more on the problems of the Hodrick and Prescott (1980, 1997) filter, see the studies by, *inter alia*, Nelson and Plosser (1982), Singleton (1988), Harvey and Jaeger (1993), King and Rebelo (1993), Jaeger (1994), Cogley and Nason (1995), Canova (1993), Cogley (2001), Pedersen (2001), and Ravn and Uhlig (2002).
[2] For more on the problems of the Baxter and King (1997, 1999) bandpass filter, see the excellent studies by Iacobucci and Noullez (2005), Harvey and Trimbur (2003), and Murray (2003).

leakage problems, this filter is time-varying and asymmetric, implying that nothing can be said about the stationarity of the filtered series, even if the original series is, itself, stationary. Furthermore, the time-dependent and frequency-dependent phase shift implies the loss of all timing relationships between any two series, a loss that can be crucial, as in the case, for instance, of Okun's law or the Phillips curve. As Christiano and Fitzgerald (1999, 2003) themselves note, once a phase shift is introduced, this changes the correlation function between the two series.[3] In contrast, Harvey and Jaeger (1993), Jaeger (1994), Harvey *et al*. (1998), and Harvey and Trimbur (2003) show that the structural time series model developed by Harvey (1985, 1989) does not suffer from these deficiencies, nor is it subject to the same criticisms levelled at the aforementioned trend and cyclical extraction methods.

This paper is organised as follows. Section 2 presents a brief survey of the literature that deals with impact of crude oil on the macroeconomy. In section 3, a brief description of Harvey's (1985, 1989) structural time series model is provided. Section 4 presents the data and discusses the empirical results, while section 5 provides some concluding remarks.

2. Crude Oil and the Macroeconomy: Related Literature

Studies analysing the relationship between crude oil and the macroeconomy fall into a number of distinct categories. The first is comprised of studies that analyse the macroeconomic effects of higher crude oil prices. Darby (1982), for instance, tests the significance of the oil price variable in an augmented Lucas-Barro real income equation, without reaching a definitive conclusion about the effects of higher oil prices. Hamilton (1983), however, appears to be in no doubt about the role played by OPEC in causing US recessions and bouts of inflation. He shows that there have been secular and cyclical

[3] For more on the problems of the Christiano and Fitzgerald (1999, 2003) 'ideal' bandpass filter, see the excellent studies by Iacobucci and Noullez (2005), Harvey and Trimbur (2003), and Murray (2003).

correlations between oil prices and US economic activity. Hamilton (1983) also provides more rigorous evidence on the basis of (Granger) causality testing in a six-variable vector autoregressive (VAR) model. He concludes that seven out of the eight post-war US recessions had been caused by sharp increases in the price of crude oil. These results were later confirmed by Hamilton (1985, 1988) and extended by Mork (1989). Similarly, Renshaw (1992) concludes that US recessions have been preceded by yearly increases in crude oil prices.

In recent times, however, Hooker (1996a) has tried to refute the results obtained by Hamilton (1983). He provides strong evidence to show that crude oil prices no longer (Granger) cause US macroeconomic variables for the post-1973 period. Hooker (1996a) explores a number of possible explanations for this finding, including the possibility of sample instability and model specification errors, as well as the endogeneity of oil prices. Hamilton (1996) responds to this by arguing that the evidence since 1983 has strengthened his earlier convictions, citing the Iraqi invasion of Kuwait as a key factor in the recession of the early 1990s. Hooker (1996b), however, does not seem to be convinced by this argument.

In a recent study, Hamilton (2009) compares the similarities and differences between the sharp increases in oil prices during 2007/08 and that of earlier oil price increases, by looking at the factors that caused them, and the effects that they had on the economy. He finds that, in contrast to previous oil price shocks, the increase in oil prices during 2007/08 was caused by strong global demand for oil in the face of stagnating world production. Hamilton (2009) shows that the consequences for the economy have been similar to those observed in earlier episodes, with significant effects on consumption spending and purchases of domestic automobiles. Without these declines in consumption spending and purchases of domestic automobile sales, he argues that it would have been unlikely that the US would have suffered a recession. As such, Hamilton (2009) concludes that this episode should be added to the list of US recessions where sharp increases in the price of oil appear to have been the cause. In a further study, Hamilton (2010) states that Iraq's invasion of Kuwait in 1990 led to a doubling in the price of crude oil, and was followed by the ninth post-war recession in 1990/91. While most practitioners are aware that the price of crude oil more than doubled in 1999/2000, he formally shows that this increase led to the tenth post-war recession, occurring in 2001. Yet another doubling in the price of oil occurred in 2007/08, which preceded the beginning of the eleventh post-war recession. As such, Hamilton (2010) states that 10 out of the 11 post-war recessions have been caused by significant oil price shocks, the exception being the mild recession of 1960/61, for which there was no preceding rise in oil prices.

Bernanke *et al*. (1997) also challenge the findings by Hamilton (1983), asserting that the response of monetary policy to each oil price increase is what caused US recessions in the post-war period. Using a seven-variable VAR model, they show that the fall in output throughout 1981 is explained by the 1979 increase in oil prices *and* the subsequent tightening of monetary policy. Furthermore, Bernanke *et al*. (1997) show that, after the beginning of 1982, the main reason why output fell was a result of the lagged effect of the tightening of monetary policy, in late 1981 and 1982. A similar view is held by, *inter alia*, Kilian (2008) and Barsky and Kilian (2002, 2004), who argue that the major increases in oil prices during the 1970s were caused by worldwide monetary expansions, that drove output levels above their potential, and were followed by periods of low real interest rates. As these booms gave way to recessions and increases in real interest rates, oil prices started falling and ultimately collapsed in 1986. Furthermore, Kilian (2008) and Barsky and Kilian (2002, 2004) claim that the major increases in oil prices during the 1970s did not contribute to the mechanism that resulted in stagflation, but rather, the combination of a stagnant economy coupled with higher domestic prices, is instead attributable to monetary factors.

The second category of studies deals with those that construct a theoretical model, in which oil is treated as either a consumption good, a standard productive input, or as a factor linked to capital utilisation. Some of the more recent contributions include, *inter alia*, Kim and Loungani (1992), Rotemberg and Woodford (1996), Finn (1995, 2000), Carlstrom and Fuerst (2006), and Leduc and Sill (2004, 2007). All of these studies, however, make the assumption that either the oil price or oil supply is exogenous, and therefore, unrelated to any economic fundamentals. Kilian (2008, 2009) argues that making this assumption is theoretically unappealing and inconsistent with the evidence presented by, *inter alia*, Hamilton (1983, 1985, 1988, 1996), Mabro (1998) and Kilian (2008, 2009). Moreover, with an exogenous oil sector and the absence of any real rigidities, there is no meaningful trade-off between stabilising the output gap and inflation, implying that full price stability is optimal even in the face of oil sector shocks (Blanchard and Galí, 2010). The fact that inflation was highly erratic during the 1970s suggests that either monetary policy was far from being optimal, or that indeed, there was an important monetary policy trade-off (Barsky and Kilian, 2002).

The third category, dealing with the macroeconomic determinants of oil consumption, is quite vast. Early studies include those by, *inter alia*, Wolf *et al*. (1981), Zilberfarb and Adams (1981), Brown (1983), Cavoulacos and Carmanis (1983), Bopp (1984), Dunkerley and Hoch (1987), Donatos and Mergos (1989), Ibrahim and Hurst (1990), and Jones (1993). However, a severe limitation of these early studies is that they generally did not pay any attention to the time series properties of the underlying variables. As a result of this, the standard errors of the estimated coefficients do not have an asymptotic normal distribution, and so inferences made based on the estimated coefficients are not reliable. In more recent times, studies by, *inter alia*, Lee *et al*. (1995), Raymond and Rich (1997), Moosa (1998) and

Bentzen (2007), directly deal with this issue, by employing more appropriate time series techniques, such as error-correction modelling and Granger-causality testing.

A fourth category deals with the phenomenon of the 'Great Moderation', in which a period of remarkable macroeconomic stability existed, reflected in a sharp fall in the volatility, and sometimes the persistence, of key macroeconomic variables in a number of countries. The beginning of this period of extraordinary stability is usually dated around 1984, and was initially noticed by, *inter alia*, Bernanke *et al*. (1997), Kim and Nelson (1999), and McConnell and Pérez-Quinós (2000). Since then, other studies have found evidence supportive of the 'Great Moderation'. For instance, Stock and Watson (2002) report evidence of volatility moderation for six OECD countries, while Cecchetti *et al*. (2005) present similar findings for 16 out of 25 industrialised countries. On the other hand, Canova *et al*. (2007) argue that evidence for the 'Great Moderation' is only seen in Anglo-Saxon countries. Nakov and Pescatori (2010) analyse the extent to which the 'Great Moderation' in the US can be explained by changes in oil shocks and in the oil elasticity of output with respect to supply, by calibrating a dynamic, stochastic, general equilibrium (DSGE) model, in which the oil sector is represented by a dominant producer (OPEC) and a fringe of competitive oil suppliers (non-OPEC), who can collectively restrain the market power of the cartel. A number of explanations have been put forward for the increased stability, including: 1). the decrease in real wage rigidities, which smooths the trade-off between inflation stabilisation and the stabilisation of the output gap; 2). the application of better monetary policy; 3). the decline in the share of oil in production and greater efficiency that may reduce the effects of oil; 4). a reduction in the exchange rate pass-through, and finally, that the recurring oil price shocks are associated with stronger global demand for crude oil.[4]

[4] See, for instance, Bernanke *et al*. (1997), Kim and Nelson (1999), McConnell and Pérez-Quinós (2000), Clarida *et al*. (2000), Blanchard and Simon (2001), Kahn *et al*. (2002), Ahmed *et al*. (2004), Kim *et al*. (2004, 2008), Summers (2005), Boivin and Giannoni (2006), De Gregorio *et al*. (2007), Galí and Gambetti (2008),

A final category includes those studies that explicitly deal with the unobserved trend, cyclical and seasonal components, in the behaviour of oil consumption. Moosa (1996a), for instance, models the demand for Japanese oil imports using a seasonal error-correction model, in which the amount of oil imports are determined by economic activity. In an extension to this study, Moosa (1996b) uses a structural time series model to analyse the cyclical and seasonal behaviour of Japanese oil imports. In a related study, Moosa (1996c) employs the Kalman filter to show that oil consumption in OECD countries is procyclical. This study is a natural extension of these earlier undertakings, in which the cyclical relationship between oil and real output is analysed, using quarterly data for the period 1984:1 to 2010:4. In particular, this study assesses the contemporaneous and non-contemporaneous cyclical comovement of the demand for oil with real output, using Harvey's (1985, 1989) structural time series model.

3. Econometric Methodology

In order to examine he relationship between oil and real output, time series data on the unobserved components, z_t^c and y_t^c is required. The approach taken in this study is to use the structural time series model developed by Harvey (1985, 1989). The rationale for using this methodology is provided by, *inter alia*, Harvey *et al*. (1998), and Harvey and Jaeger (1993). First, this approach allows investigators to deal explicitly with seasonal and irregular movements. This is important because if these two components are not dealt with properly, they may distort the cyclical component. Second, it provides the most useful framework within which to present stylized facts on time series, as it is explicitly based on the stochastic properties of the data. Finally, it provides useful information and serves as a basis for

Hamilton (2009), Kilian (2009), Herrera and Pesavento (2009), Blanchard and Galí (2010), Nakov and Pescatori (2010), and Crucini *et al*. (2011).

exposing the limitations of other techniques. The structural times series model may be written as:

$$z_t = \mu_t + \varphi_t + \varepsilon_t \qquad (1)$$

where z_t is the observed value of the series, μ_t is the trend component, φ_t is the cyclical component, and ε_t is the irregular component.[5] The trend and cyclical components are assumed to be uncorrelated, while ε_t is assumed to be white noise.

The trend component, which represents the long-term movement of a series, is assumed to be stochastic and linear. This component can be represented by the following equations:

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \qquad (2)$$

$$\beta_t = \beta_{t-1} + \zeta_t \qquad (3)$$

where η_t ~ NID $(0, \sigma_\eta^2)$, and ζ_t ~ NID $(0, \sigma_\zeta^2)$. The trend component, μ_t, is a random walk with a drift factor, β_t, which follows a first-order autoregressive process represented by equation (3). This process collapses to a simple random walk with drift if $\sigma_\zeta^2 = 0$, and to a deterministic linear trend if $\sigma_\eta^2 = 0$ as well. If, on the other hand, $\sigma_\eta^2 = 0$ while $\sigma_\zeta^2 \neq 0$, the process will have a trend that changes relatively smoothly.

The cyclical component, which is assumed to be a stationary linear process, may be represented by:

$$\varphi_t = a\cos\theta t + b\sin\theta t \qquad (4)$$

where t is time, and the amplitude of the cycle is given by $(a^2 + b^2)^{1/2}$. To make the cycle stochastic, the parameters a and b are allowed to evolve over time, while continuity is

[5] The time series observations on oil consumption and real output used in this study have been seasonally adjusted, and so the seasonal component has been excluded from the model.

preserved by writing down a recursion for constructing φ_t before introducing the stochastic components. By introducing disturbances and a damping factor, we obtain:

$$\varphi_t = \rho(\mu_{t-1} \cos\theta + \mu^*_{t-1} \sin\theta) + \omega_t \tag{5}$$

$$\varphi^*_t = \rho(-\mu_{t-1} \sin\theta + \mu^*_{t-1} \cos\theta) + \omega^*_t \tag{6}$$

where φ^* appears by construction such that ω_t and ω^*_t are uncorrelated white noise disturbances with variances σ^2_ω and $\sigma^2_{\omega^*}$, respectively. The parameters $0 \le \theta \le \pi$ and $0 \le \rho \le 1$ are the frequency of the cycle and the damping factor on the amplitude, respectively. In order to make numerical optimisation easier, the constraint $\sigma^2_\omega = \sigma^2_{\omega^*}$ is imposed.

The extent to which the trend and cyclical components evolve over time depends on the values of σ^2_η, σ^2_ζ, σ^2_ω, θ, and ρ, which are known as hyperparameters. These hyperparameters, along with the components, can be estimated by maximum likelihood using the Kalman filter to update the state vector. This procedure requires writing the model in state space form. Related smoothing algorithms can be used to obtain the estimates of the state vector at any point in time within the sample period.

The model presented as equation (1) may be augmented to include explanatory variables. In this case, equation (1) may be rewritten as:

$$z_t = \mu_t + \varphi_t + \beta' X_t + \varepsilon_t \tag{7}$$

where β' is $k \times 1$ vector of unknown parameters and X_t is a $k \times 1$ vector that contains k independent variables. If the independent variables have a high degree of explanatory power for the dependent variable, z_t, then they should be able to explain it trend and cyclical variation, and so μ_t would reduce to a constant term and φ_t would be unnecessary.

4. Data and Empirical Results

The data used in this study are quarterly observations for the OECD, covering the period 1984:1 to 2010:4. Demand for crude oil, z_t, is measured in one thousand barrels per day, and is extracted from the Energy Information Administration's website, at the US Department of Energy.[6] The variable for real output, y_t, is real GDP measured in millions of 2000 US dollars, and is taken from the OECD Quarterly National Accounts data base. For the purposes of this study, both variables are measured in natural logarithms.

In order to analyse the cyclical relationship between the demand for crude oil and real output, the empirical analysis will be conducted in two stages. The first stage is to estimate the model represented by equation (7) in the frequency domain, while the second is to extract the cyclical components, and test the relationship between them, using the ordinary least squares (OLS) procedure.

In undertaking the first stage of the analysis, three different specifications of equation (7) will be estimated, by defining the vector, X_t, differently.[7] In the first specification, the dependent variable is the demand for crude oil, z_t, while the vector, X_t, is defined to include the contemporaneous value, as well as four lags, of real output, y_t, that is $X_t^{'} = [y_t \quad y_{t-1} \quad y_{t-2} \quad y_{t-3} \quad y_{t-4}]$. In this case, the model may be written as:

$$z_t = \mu_t + \varphi_t + \alpha_1 y_t + \alpha_2 y_{t-1} + \alpha_3 y_{t-2} + \alpha_4 y_{t-3} + \alpha_5 y_{t-4} + \varepsilon_t \qquad (8)$$

One advantage of his specification is that it makes it possible to find out if real output is capable of explaining the trend as well as the cyclical variation in the demand for oil. In an

[6] The data on the demand for crude oil can be downloaded at http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=50&pid=54&aid=2.

[7] These specifications are similar to those used by, *inter alia*, Moosa (1996c) and De Gregorio *et al*. (2007).

attempt to concentrate on the cyclical component, a second version of equation (7) is specified, in terms of first differences. This version of the model may be written as:

$$\Delta z_t = \mu_t + \varphi_t + \alpha_1 \Delta y_t + \alpha_2 \Delta y_{t-1} + \alpha_3 \Delta y_{t-2} + \alpha_4 \Delta y_{t-3} + \alpha_5 \Delta y_{t-4} + \varepsilon_t \qquad (9)$$

The third version of equation (7) is obtained by defining the vector X_t, not only to include the variables Δy_t, Δy_{t-1}, …, Δy_{t-4}, but also an error correction term, ς_{t-1}, so that $X_t' = [\Delta y_t \quad \Delta y_{t-1} \quad \Delta y_{t-2} \quad \Delta y_{t-3} \quad \Delta y_{t-4} \quad \varsigma_{t-1}]$. In this case, the model may be specified as:

$$\Delta z_t = \mu_t + \varphi_t + \alpha_1 \Delta y_t + \alpha_2 \Delta y_{t-1} + \alpha_3 \Delta y_{t-2} + \alpha_4 \Delta y_{t-3} + \alpha_5 \Delta y_{t-4} + \gamma \varsigma_{t-1} + \varepsilon_t \qquad (10)$$

where $\varsigma_t = z_t - y_t$.

The results of estimating equations (8), (9) and (10) are presented in Table 1, which shows the estimated values of the hyperparameters, their t-statistics in parenthesis, as well as some measures of the goodness of fit and various diagnostic tests. These include the standard error of the equation, $\tilde{\sigma}$, the prediction error variance, $\tilde{\sigma}^2$, the Durbin-Watson, DW, statistic, the coefficient of determination, R^2, the coefficient of determination based on the variance of the first differences of the dependent variable, R_D^2, the Akaike information criterion, AIC, the Bayesian information criterion, BIC, the Ljung-Box (1978) $Q(P,d)$ statistic, which is based on the first P residual autocorrelations and is approximately distributed as χ_d^2, and the Doornik-Hansen (1994) $N(d)$ statistic for normality based on the third and fourth moments of the distribution, and is approximately distributed as χ_2^2 under the null hypothesis. The last diagnostic test statistic reported is the simple non-parametric $H(h)$ test used to detect the presence of heteroscedasticity. It is calculated as the ratio of the squares of the last h residuals to the squares of the first h residuals, where h is the closest integer to one-third of the sample size, and is approximately distributed as $F(h,h)$.

[Insert Table 1 about here]

The measures for the goodness of fit show that the three estimated equations are very well determined, with each model passing the diagnostic tests for serial correlation, normality and heteroscedasticity. The values of the cyclical components, φ_t and φ_t^*, are almost equal to zero in magnitude, and are statistically insignificant in each equation, suggesting that the cyclical variation in the demand for oil can be adequately explained by the cyclical variation in output. Furthermore, the coefficient on the error correction term, γ, in equation (10), is highly significant and statistically large, implying that OECD countries adjust their demand for oil so as to maintain a desired level of intensity.

[Insert Figure 1 about here]

The second stage of the empirical analysis involves the extraction of the cyclical components of the demand for oil and real output, to solely analyse the relationship between them, in isolation from other components. These components are plotted in Figure 1, and tend to show that they are highly correlated. More formal evidence on this relationship can be obtained by estimating the following equation:

$$z_t^c = \beta_0 + \beta_1 y_t^c + \beta_2 y_{t-1}^c + \beta_3 y_{t-2}^c + \beta_4 y_{t-3}^c + \beta_5 y_{t-4}^c + \xi_t \qquad (11)$$

where the superscript, c, denotes the cyclical components of the respective variables. An advantage of this specification is that it makes it possible to assess the contemporaneous and non-contemporaneous cyclical comovement with real output, for up to four lags. In particular, if the estimated coefficient is significantly largest, in absolute terms, at time period t, then the demand for oil is contemporaneously correlated with real output. If, however, the estimated coefficient is significantly largest, in absolute terms, for time period $t-i$, where $i = 1,...,4$, then the demand for oil leads the cycle by i quarters.

Since these components are stationary by construction, OLS will produce consistent estimates of the regression coefficients, so that the estimated t-statistics will have an asymptotic normal distribution, and that the conventional model diagnostic tests will be valid. The estimated equation is:

$$z_t^c = -5.980\times10^{-4} + 0.697 y_t^c - 0.038 y_{t-1}^c - 0.045 y_{t-2}^c + 0.339 y_{t-3}^c - 0.222 y_{t-4}^c$$
$$\quad (-0.812) \quad (2.578) \quad (-0.095) \quad (-0.111) \quad (0.853) \quad (-0.808)$$

$$\overline{R}^2 = 0.241 \quad FF\left[\chi^2(1)\right] = \underset{[0.214]}{1.542} \quad HS\left[\chi^2(5)\right] = \underset{[0.419]}{4.972} \quad N\left[\chi^2(2)\right] = \underset{[0.422]}{1.724} \quad SC\left[\chi^2(4)\right] = \underset{[0.054]}{9.312}$$

where FF, HS, N and SC are the diagnostic test statistics for functional form, heteroscedsticity, normality and serial correlation, respectively. All of these tests are distributed as a χ^2 statistic, with the relevant degrees of freedom given in parenthesis and their respective marginal significance levels given in square brackets underneath.

The equation has good explanatory power, and passes all of the diagnostic tests, showing that there is a positive and significant relationship between the cyclical components of the demand for oil and real output. Furthermore, the results show that the demand for oil is procyclically contemporaneous. This result is highly supportive of that found by, *inter alia*, Moosa (1996c), Kim *et al*. (1999, 2008), McConnell and Pérez-Quinós (2000), Leduc and Sill (2004, 2007), and Nakov and Pescatori (2010), who also find that the demand for oil is procyclically contemporaneous.[8] Moreover, the relationship appears to be stable, as the equation passes the CUSUM and CUSUMSQ tests for structural stability, as shown in Figures 2 and 3, respectively.

[Insert Figure 2 about here]

[Insert Figure 3 about here]

This finding, that the demand for oil is procyclically contemporaneous, implies that consuming countries cannot stockpile oil reserves to buffer against the cyclical nature of demand, because the relationship between the demand for oil and real output is procyclically

[8] The studies by Kim *et al*. (1999, 2008), McConnell and Pérez-Quinós (2000), Leduc and Sill (2004, 2007), and Nakov and Pescatori (2010), all focus on the US, while the study by Moosa (1996c) focuses on the OECD.

contemporaneous and not countercyclical. From the perspective of oil producing countries, this result suggests that economic recessions lead to weak and bearish oil markets, because oil consuming countries cannot smooth out their demand for oil on an intertemporal basis.

5. Concluding Remarks

In this study, the cyclical relationship between the demand for oil and real output is analysed using the structural time series model developed by Harvey (1985, 1989). The empirical results show that there exists strong and positive cyclical relationship between the two variables, with the demand for crude oil being procyclically contemporaneous.

An important implication of this finding is that consuming countries cannot stockpile oil reserves to buffer against the cyclical nature of demand, because the relationship between the demand for oil and real output is procyclically contemporaneous and not countercyclical. On the other hand, oil producing countries will face weak and bearish oil markets during economic recessions, because oil consuming countries cannot smooth out their demand for oil on an intertemporal basis.

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Table 1: Frequency Domain Estimates of the Structural Time Series Models

Variable/Statistic	***Equation (8)***	***Equation (9)***	***Equation (10)***
μ_t	5.422	-0.003	-9.210*

	(1.843)	(-1.271)	(-15.268)
β_t	-0.005*	-0.000	-0.007*
	(-2.980)	(-1.664)	(-3.286)
φ_t	0.018	7.929×10^{-4}	0.001
	(0.442)	(0.196)	(0.343)
φ_t^*	0.005	-0.003	0.001
	(0.127)	(-0.157)	(0.324)
y_t	0.527		
	(1.697)		
y_{t-1}	0.301		
	(0.577)		
y_{t-2}	-0.601		
	(-1.153)		
y_{t-3}	0.783		
	(1.509)		
y_{t-4}	-0.703*		
	(-2.230)		
Δy_t		-0.407	0.778*
		(-0.856)	(1.598)
Δy_{t-1}		1.602*	0.046
		(2.786)	(0.161)
Δy_{t-2}		-0.883	-0.558*
		(1.558)	(-2.048)
Δy_{t-3}		0.203	0.012
		(0.357)	(0.041)
Δy_{t-4}		-0.278	0.040
		(-0.584)	(0.141)
ς_{t-1}			-1.402*
			(-15.258)
$\tilde{\sigma}$	0.0132	0.0210	0.0128
$\tilde{\sigma}^2$	1.750×10^{-4}	4.390×10^{-4}	1.650×10^{-4}
DW	1.8978	2.8007	1.9936
R^2	0.9767	0.9636	0.9638
R_D^2	0.8550	0.8305	0.9365
AIC	-8.4189	-7.4972	-8.4597
BIC	-8.1137	-7.1902	-8.1272
$Q(11,6)$	9.611	6.680	10.659
$N(2)$	5.8436	0.8248	1.9719
$H(34)$	0.5652	0.5839	0.4799

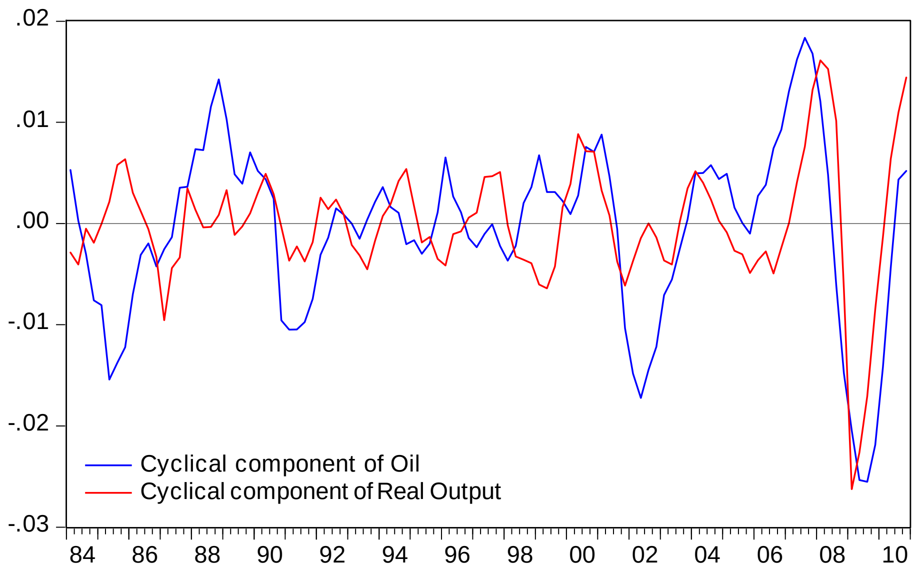

Figure 1: The Cyclical Components for Real Output and the Demand for Oil

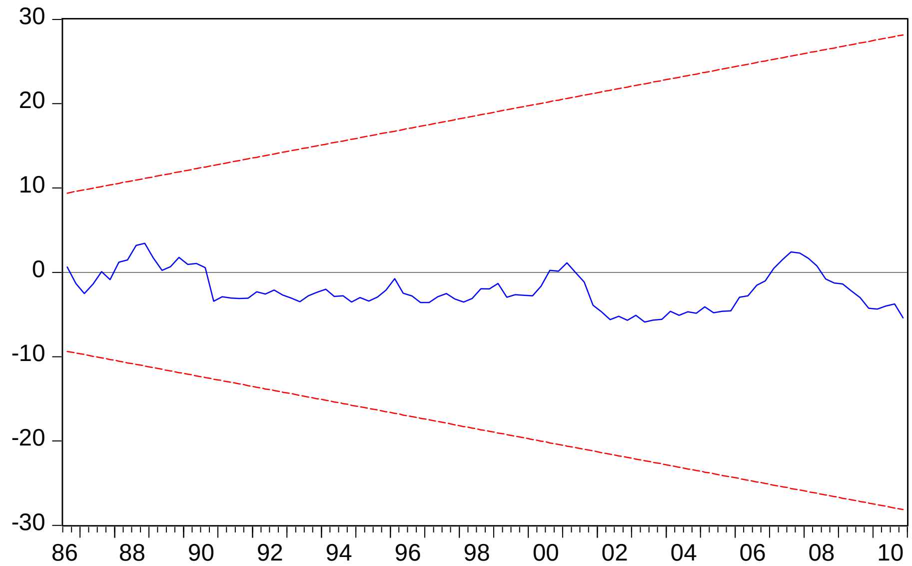

Figure 2: The Cumulative Sum of the Recursive Residuals

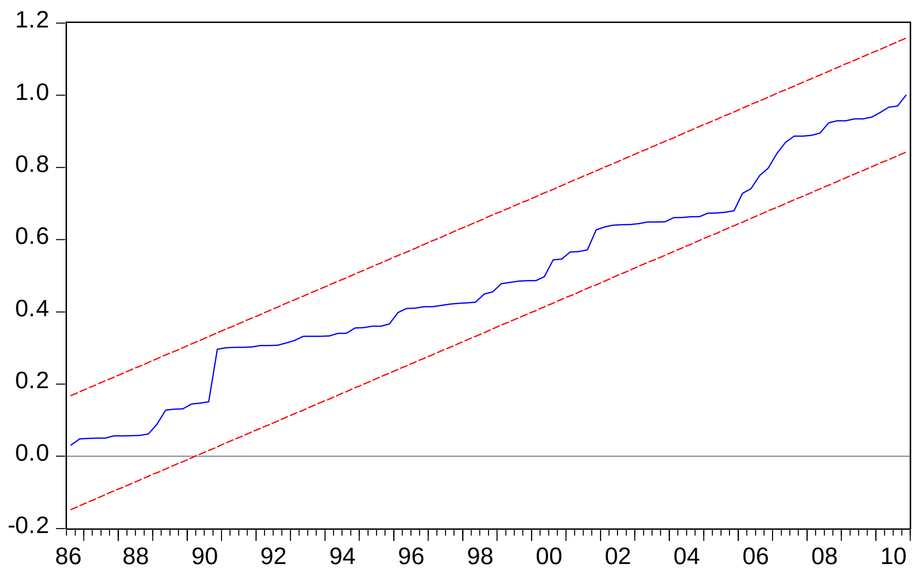

Figure 3: The Cumulative Sum of the Squared Recursive Residuals