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Price Relationships in the Petroleum Market: An Analysis of Crude Oil and Refined Product Prices

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Abstract

In this paper the relationships between crude oil and refined product prices are investigated in a multivariate framework. This allows us to test several (partly competing) assumptions of earlier studies. In particular, we find that the crude oil price is weakly exogeneous and that the spread is constant in some but not all relationships. Moreover, the multivariate analysis shows that the link between crude oil prices and several refined product prices implies market integration for these refined products. This is an example of supply driven market integration and producers will change the output mix in response to price changes.

JEL Classification: E32

Keywords: Oil prices, value chain, market integration, cointegration

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Introduction

Recently, several studies have investigated the relationship between the prices of crude oil and refinery products. These studies have established the existence of long-run price relationships between crude oil and refined products (Serlitis, 1994; Grima and Paulson, 1999; Gjølberg and Johnsen, 1999). Insights to these relationships convey valuable information for forecasting and risk management in the oil industry. The relationship between crude oil and refined products will in general make the risk management problems multivariate which is of particular interest for integrated oil companies, managing a portfolio of oil assets.

However, previous analyses in the literature have often been carried out in a single equation framework based on the implicit assumption of weak exogeneity of at least one of the relevant variables (assets)[1]. Intuitively, weak exogeneity of variables means that no useful information is lost when conditioning on these variables without specifying their generating process. Modeling, for instance, crude oil prices as exogenous is hence based on the assumption that it is the price of crude oil that determines product prices, and that changes in crude prices will map directly to product prices whilst changes in product prices are not thought to feeding back to crude oil prices. Although some market structures might give support to this conclusion it is not *a priori* obvious that this assumption always holds. Generally, when investigating the relationship between prices economic theory does not provide any guidance with respect to which variable should be chosen as exogenous (see e.g. Goodwin, Grennes and Wohlgenant, 1990a; 1990b). It is therefore just as well possible to argue that it is the

[1]When estimating relationships in single equation specifications, one implicitly assumes that the right hand side variables are exogenous.

demand for refinery products that is driving the crude oil price or that the relationship goes in both directions[2].

Another issue that is generally not addressed in the literature is the difference between long-run relationships and spreads. A long-run relationship implies that if the price of one product is moving in one direction, the other will follow. However, for this long-run relationship to become a spread the parameter on the log of the right hand side price in a bivariate relationship must be equal to one, so that the prices move proportionally to each other.[3] Girma and Paulson (1999) and Gjølberg and Johnsen (1999) address this issue by reporting results both for general long-run relationships and when the spread restriction has been imposed. However, although the fact that the spreads are cointegrated provides an indication that these parameter restrictions hold, it cannot be interpreted as a statistical test.

The main reason for these shortcomings is the choice of econometric method. Often a simple Engle and Granger test (Engle and Granger, 1987) is used to test for cointegration in combination with error correction models (ECM) in order to draw inference. This approach, although appealing for its simplicity runs into difficulties, especially if the analysis is multivariate. It requires an exogeneity assumption and is incapable of testing hypotheses on the estimated parameters since ordinary inference theory is not valid (Banerjee *et al*, 1993).

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[2] This has led many researchers either to arbitrarily make exogeneity assumptions or to run regressions in both directions, sometimes yielding conflicting results.
[3] If there are more then one variable at the right hand side, the parameters must sum to unity (Engsted and Tanggaard, 1994).

Moreover, given that there are several refined products, single equation specifications cannot in general capture all the relevant information[4].

In this paper we will show that more information about the market structure for crude oil and refined products can be obtained by carrying out the analysis in a multivariate framework. Cointegration tests will therefore be conducted in a Johansen framework (Johansen, 1988, 1991).[5] We will then be able to test whether there is a long run relationship between crude oil and refined product prices and whether the spreads are constant. Moreover, if such a relationship is found, we will test for price leadership by testing whether crude or any of the refined product prices are weakly exogenous. This is of interest for several reasons. It provides an assessment of the appropriateness of previous modeling attempts as well as it potentially facilitates forecasting of crude and product prices.

Finally a closer look will be taken at the relationships of prices of refined products. This is of interest since a number of market definitions are also based on relationships between prices. For instance Stigler (1969, p. 85) defines a geographic market as "the area within which the price of a commodity tends to uniformity, allowance being made for transportation costs". Stigler and Sherwin (1985) note that a similar relationship will hold for different qualities, but where quality differences have the same role as transportation costs. The fact that there seems to be a long-run relationship between crude oil prices and the price for different refined products also indicates that there is a long-run relationship between the prices of the refined products. This market integration then implies that changes in crude prices not only have the

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[4] Serletis (1994) conducts a multivariate analysis on the futures prices of crude oil and refinery products. However, apart from interpreting the cointegration vectors as evidence of a long-run relationship, he does not test any hypothesis on the parameters.

[5] Most recent studies indicate that the prices are nonstationary, and hence, that cointegration analysis is the appropriate econometric framework (e.g. Serleltis, 1994, Girma and Paulson, 1999, Gjølberg and Johnsen, 1999)

potential to change price levels of the refined products. It is also an example of supply driven market integration, as producers of refined products responds to changes in relative prices by adjusting the product mix.

The paper is organized as follows; the following section will give an exposition of the underlying theory and the model used in the empirical analysis, and an outline of the testing procedure used to test different behavioral hypotheses. This will be followed by the empirical analysis and a discussion of the results and their implications. A final section will summarize the results and will draw final conclusions.

Methodology

The basic relationship to be investigated when analyzing relationships between two different prices (p_1) and (p_2) observed at time (t) is

$$\ln p_{1t} = \alpha + \beta \ln p_{2t} \tag{1}$$

where α is a constant term (the log of a proportionality coefficient) that captures differences in the levels of the prices and β gives the relationship between the prices. If β=0, there is no relationship between the prices. If β=1 the spreads are constant if the products are at the same level in the market chain. The relative prices between the refined products are constant if the prices are at the same level.[6] In this case the goods in question are perfect substitutes. If β is different from zero and different from unity there exists a relationship between the prices, but the spread or the relative price is not constant. Equation (1) describes the situation when prices adjust immediately. However, often there will be a dynamic adjustment pattern. This can be accounted for by introducing lags of the two prices (Ravallion, 1986, Slade, 1986). It

[6] That the relative prices are constant implies that the goods are perfect substitutes. This is also often labeled as the (relative) Law of One Price, as it implies that the prices are proportional.

should be noted here that even when dynamics are introduced, the long-run relationship will have the same form as equation (1).

Traditionally, relationships like equation (1) or its dynamic counterpart have been estimated with ordinary least squares (OLS). However, since the late 1980s it has become evident that traditional econometric tools cannot be used, when prices series are nonstationary, since normal inference theory breaks down (Engle and Granger, 1987). Instead cointegration analysis is the appropriate tool to infer causal long-run relationships between nonstationary time series.

The cointegration approach may be represented as follows.[7] Consider the two price series, P_{1t} and P_{2t}. Each price series is by itself nonstationary and is required to be differenced once to produce a stationary series. In general, a linear combination of nonstationary data series will be nonstationary. In this case there is no long-run relationship between the data series. However, when the data series form a long-run relationship, the data series will move together over time, and a linear combination of the data series,

$$P_{1t} - \Psi P_{2t} = \varepsilon_t , \qquad (2)$$

will produce a residual series ε_t which is stationary. In this case, the prices p_{1t} and p_{2t} are said to be cointegrated, with the vector $[1,\psi]$ as the cointegration vector (Engle and Granger, 1987). This is straightforward to extend to a multivariate case.

Two different tests for cointegration are commonly used in the literature. They are the Engle and Granger test (Engle and Granger, 1987) and the Johansen test (Johansen, 1988; 1991). In

[7] See e.g. Hendry an Juselius (2000) for a more thourough discussion about modelling of nonstationary data series and cointegration.

this study the latter will be used, since it allows for hypothesis testing on the parameters in the cointegration vector.

The Johansen test is based on a vector autoregressive (VAR) system. A vector, $\boldsymbol{P_t}$, containing the N prices to be tested for cointegration is assumed to be generated by an unrestricted k^{th} order vector autoregression in the levels of the variables;

$$P_t = \Pi_1 P_{t-1} + \ldots + \Pi_k P_{t-k} + \mu + e_t, \qquad (3)$$

where each of the Π_i is a $(N \times N)$ matrix of parameters, μ a constant term and $\varepsilon_t \sim iid(0,\Omega)$.

The VAR system of equations in (3) written in error correction form (ECM) is;

$$\Delta P_t = \sum_{i=1}^{k-1} \Gamma_i \Delta P_{t-i} + \Pi_k P_{t-k} + \Phi D_t + \mu + e_t \qquad (4)$$

with $\Gamma_i = -I + \Pi_1 + \ldots + \Pi_i$, $i = 1, \ldots, k-1$ and $\Pi_K = -I + \Pi_1 + \ldots + \Pi_k$. Hence, Π_K is the long-run 'level solution' to (3). If $\boldsymbol{P_t}$ is a vector of $I(1)$ variables, the left-hand side and the first (k-1) elements of (4) are $I(0)$, and the last element of (4) is a linear combination of $I(1)$[8] variables. Given the assumption on the error term, this last element must also be $I(0)$; $\Pi_K P_{t-k} \sim I(0)$. Hence, either $\boldsymbol{P_t}$ contains a number of cointegration vectors, or Π_K must be a matrix of zeros. The rank of Π_K, r, determines how many linear combinations of $\boldsymbol{P_t}$ are stationary. If $r=N$, the variables in levels are stationary; if $r=0$ so that $\Pi_K=0$, none of the linear combinations are stationary. When $0<r<N$, there exist r cointegration vectors—or r stationary linear combinations of $\boldsymbol{P_t}$. In this case one can factorize Π_K; $-\Pi_K = \alpha\beta'$, where both α and β are $(N \times r)$ matrices, and β contains the cointegration vectors (the error correcting

[8] A series is said to be integrated of order one, i.e. $I(1)$if it has to be differenced once in order to induce stationarity of the variable. If a variable has to be differenced n times to become stationary it is said to be integrated of order $I(n)$. The order of integration will depend on the unit root it contains.

mechanism in the system) and α the adjustment parameters. Two asymptotically equivalent tests exist in this framework to determine the rank of Π, the trace test and the maximum eigenvalue test.

The Johansen procedure also allows hypothesis testing on the coefficients α and β, using likelihood ratio tests (Johansen and Juselius, 1990). More specifically, in the bivariate case there are two price series in the $\boldsymbol{P}_t$ vector. Provided that the price series are cointegrated, the rank of $\Pi = \alpha\beta'$ is equal to 1 and α and β are 2x1 vectors. In this case, testing the restriction $\beta'=(1,-1)'$ provides a test of constant spreads or whether the relative prices are constant. The α vector contains information about weak exogeneity. When both elements in the α vector are different from zero, there will be causality in both directions and the two price series should be modeled as a system. However, if one of the elements is zero, there will be no long-run causation towards this variable in the system, and hence, this variable will be weakly exogenous in the system. The variable will be strongly exogenous if it in addition is not affected by the short-run dynamics of other variables in the system.

In the multivariate case, if all prices have the same stochastic trend, there must be (*n*-1) cointegration vectors in the system. This follows from Stock and Watson (1988) who show that in a system with *n* variables, if there are *r* cointegration vectors there must be *(n-r)* stochastic trends. It then follows from the identification scheme of Johansen and Juselius (1992) that each cointegration vector can be represented so that all but two elements are zero.[9] This gives each long-run relationship the form of equation (1). However, since the cointegration vectors are identified only up to a nonsingular transformation, which

[9] See Asche, Bremnes and Wessells (1999) for a discussion of these issues in a market integration context.

normalization is used is still arbitrary. When the identifying normalization is imposed, in the case with three price series, one representation of the matrix of cointegration vectors is:

$$\beta = \begin{bmatrix} 1 & 1 \\ -\beta_1 & 0 \\ 0 & -\beta_2 \end{bmatrix} \tag{5}$$

If both β parameters are equal to 1, the spreads or the relative prices are constant. Moreover, in a system with *n* data series and *r* cointegration vectors, there can be at most *(n-r)* weakly exogenous variables in the system (Johansen and Juselius, 1994). This implies that if there is a long-run relationship between the crude oil price and all the refined product prices, there can be at most one exogenous variable in the system.

The Data

The analysis will be based on monthly price series of crude oil and four major oil products in the period of January 1992 to November 2000. The focus will be on the North West European market. The crude oil will be Brent, i.e. crude oil originating from the UK continental shelf and product prices will be from the Rotterdam market for gas oil, heavy fuel oil, naphtha and kerosene.[10] Rotterdam prices are generally accepted as a base to price oil products in trade and in internal company transfer throughout northern Europe[11]. Spot prices are chosen since trade in spot prices results in physical delivery and hence limit speculative aspects that are present in the corresponding futures prices. All product prices will be in US$ per metric ton, whilst Brent prices will be in US$ per barrel.

[10] The Rotterdam market is the generic term given to trade in oil products in northwest Europe and takes its name from the large refining and storage complex in the Antwerp, Rotterdam, and Amsterdam area.
[11] The predominance of the Rotterdam spot market in Europe has been established for example in a study by Indjehagopian and Simon (2000) for the price development of heating oil in France and Germany.

Figure 1 and 2 depict the corresponding developments in crude oil and the four oil product prices during the period of 1992-2000. As the figures show, product prices seem to be correlated with crude oil prices. It can however, also be seen that substantial short-term price volatility exists, which may be due to short-term tightness in a particular market. It is also interesting to note that fuel oil seems to be less correlated with the other three products. This may be due to the fact that fuel oil faces a high degree of possible substitution to other fuels in its main use, i.e. power generation. It therefore soon hits an upper limit beyond which substitution would reduce prices again (Horsnell and Mabro, 1993). There appears also to be a high degree of co-movement between gas oil and kerosene. This is, however, not too surprising since both are distillates coming from almost the same part of the crude barrel and a refinery has to reduce the production of gas oil in order to increase the production of kerosene.

Some stylized facts might provide some further indication about underlying relationships and table 1 reports means and the coefficients of variation for crude and the different product prices. Kerosene is yielding the highest prices, followed by naphtha and gas oil. Although mean prices differ, the coefficients of variation are nevertheless in the same range.

Before conducting any econometric analysis, the time series properties of the data must be investigated. This is done using an Augmented Dickey Fuller (ADF) test, based on critical values provided by MacKinnon (1991). The lag length will be chosen as suggested by Benerjee (1993) by starting with a generous parameterization and then removing insignificant lags. Table 2 reports the results of the ADF tests for a lag length of 10 for prices in levels and a lag length of 4 for prices in first differences.[12] The test indicates that while prices in levels

[12] The results are insensitive to the choice of lag length.

are nonstationary, all prices are stationary in first differences. The analysis will therefore proceed under the assumption that all price series are integrated of order one.

Econometric Results

Since the price series are all nonstationary and integrated of the same order, cointegration analysis is the appropriate tool to investigating the relationships between the prices. The Lag length was again chosen to whiten the error term and as tests for autocorrelation suggested three lags were sufficient. Lagrange multiplier tests (LM) for the presence of autocorrelation up to the 12^{th} order and Jarque – Bera tests of normality are reported in table 3

The two tests to determine the rank of the coefficient matrix Π, i.e. the trace and eigenvalue test, are reported in table 4 Both test statistics have non-standard distributions, which are functionals of the multivariate Wiener process. Critical values have been tabulated by Johansen (1988) and Osterwald – Lennum (1992).

Both the maximum eigenvalue test and the trace test suggest that there are three cointegration vectors in this system, and accordingly, two stochastic trends. This result has two possible interpretations. Either one of the price series in the system has an independent stochastic trend and therefore does not belong in the system, or for some price series the relationship is weaker then the bivariate relationship suggested in equation (1). To infer which of the prices are linked by the same stochastic trend, bivariate cointegration tests were conducted. Since there are more potential pairs than uniquely identified cointegration vectors, all potential pairs were estimated. The results reported in table 5 indicate that heavy fuel oil is not cointegrated with any of the other prices, suggesting that the price for this product is independent of the crude oil price.[13] [14] Since all the other prices appear to be cointegrated with the crude oil price, and with exception of naphtha and kerosene also with each other, this seems to indicate that these price series have the same stochastic trend. In order to test for cointegration of crude oil and the remaining refinery product prices, the multivariate cointegration test is therefore repeated, however this time excluding heavy fuel oil. Misspecification tests of the reduced model with three lags are reported in table 6 and the cointegration tests are reported in table 7. The cointegration tests indicate three cointegration vectors in this system, and consequently all the prices seem to follow the same stochastic trend.

Hence, the results from the cointegration analysis indicate that there exists a long-run relationship between the crude oil price and the prices of gas oil, kerosene and naphtha, but not between crude oil and heavy fuel oil. A close relationship between the prices of gas oil, kerosene and naphtha is also found, implying that the markets for these products are integrated. This link is most likely caused by the fact that with a given amount of the primary input, crude oil, one can only increase the production of one of these refined products by decreasing the production of the others. Hence, this seems to be an example of supply driven market integration, as refineries will adjust their output mix to changes of the demand in the refined products markets. The missing link between these products and heavy fuel oil implies that this sort of consideration is not important with respect to the quantity produced of heavy fuel oil.

[13] Also Gjølberg and Johnsen (1999) provide some evidence against the relationship between the prices of heavy fuel oil and crude oil.
[14] Please also note that the prices of kerosene and naphtha are not cointegrated, although both seems to have the same stochastic trend as crude oil. Hence, the bivariate tests do not give fully consistent results.

Two further issues, exogeneity of variables in the system and the determination of spreads between crude oil prices and product prices are of interest to obtain more information about the long-run relationships found in this analysis.

Exogeneity

A test for weak exogeneity will give information with respect to whether any of the products are price leaders. As discussed in section 2, tests on the factor loading parameters will determine whether any of the variables can be considered as weakly exogenous in the system. The null hypothesis to be tested is that the α matrix in a particular row is containing only zeros, and is tested with a likelihood ratio test.

The results are reported in table 8 and indicate that weak exogeneity cannot be rejected for crude oil, while it is clearly rejected for the other three products. These results suggest that crude oil is the driving factor in the price generating process and that it is crude oil that binds the price series together in the long-run. Furthermore, it indicates that the relationships between crude oil and the refined products can be modeled in single equation specifications. However, in contrast to earlier approaches such as e.g. Girma and Paulson (1999) the crude oil price should be used on the right hand side and the different refined product prices on the left hand side.

While weak exogeneity of crude oil prices can facilitate modeling of refined product prices since it makes the models simpler, it also implies that refined products prices cannot be used to forecast crude prices in the long-run. For this to be the case also in the short-run, the crude oil price must be strongly exogenous and hence not affected by the short-run movements in the refined product prices.[15] A test for the null hypothesis that the short-run movements in the refined product prices do not affect the crude price gave a test statistic of *34.327*. As this is distributed as $F\ (9,\ 92)$ with a *p*-value of 0.0000, we can reject the null hypothesis of strong exogeneity of the crude oil price. This implies that feedback mechanisms exist and hence that past variations in product prices do affect present variations of crude oil prices in the short-run. Accordingly, refined product prices may be helpful in forecasting crude oil prices in the short run.

Spreads and relative prices

Finally we address the issue whether the refined products and the crude oil prices for which a long-run relationship was found are proportional, i.e. whether the spreads and relative prices are constant. In the reduced system this likelihood ratio test is distributed as $\chi^2(3)$ and gives a test statistic of 22.289 with a *p*-value of 0.0001. Hence, the hypothesis that all the prices are proportional can be rejected. To obtain more information about these relationships, we also test for price proportionality in bivariate relationships between the crude price and the refined product prices. The results are reported in table 9. The hypothesis of price proportionality is clearly rejected between Brent and Naphtha, but not in the other two tests. This result is supported in a multivariate analysis as a test for price proportionality between crude, gas oil and kerosene. The test statistic, distributed as $\chi^2(2)$ of 1.862 with a *p*-value of 0.394 implies that we cannot reject the hypothesis that these three prices are proportional. These results indicate that changes in crude oil prices are fully reflected in the prices of gas oil and kerosene, but only partly in naphtha. Furthermore, demand changes for either gas oil or kerosene are fully reflected also in the production of the other products. However, naphtha is

[15] See Hendry (1996) for a discussion of different exogeneity concepts and their implications.

only partially influenced by demand changes for those two products, and demand changes for naphtha are only partially affecting the other two products.

Concluding remarks

Using multivariate Johansen tests to investigate the relationships between the prices of crude oil and refined products respectively, enables us to test several assumption and competing hypothesis of earlier studies on this issue. Our results indicate that while there is a long-run relationship between the prices of crude oil and gas oil, kerosene and naphtha in northern Europe for the time period studied, there does not seem to exist a similar relationship between crude oil and heavy fuel oil. There is also a long-run relationship between the prices of gas oil, kerosene and naphtha, implying that demand changes for one of these products will influence the optimal refinery output mix. However, since no such relationship between the prices of any of these products and the price of heavy fuel oil is found, the production of heavy fuel oil will not be affected by or affect demand for the other refined products.

For the three refined products for which a price relationship exists, we find the crude oil price to be weakly exogenous. This implies that one can model these relationships in single equations, as has been done in most of the existing literature. However, being exogenous the crude oil price should be the right hand side variable. Furthermore, and possibly more interesting, the weak exogeneity result implies that in the long-run, changes in crude oil prices feed through to these refined product prices, while the reverse is not true. Feedback mechanisms were however found to exist in the short run, implying that refined product prices do influence the crude oil price in the short-run. We also found the relationships between the price of crude oil and gas oil and kerosene to be proportional, implying constant spreads. This was not the case for the relationship between crude oil and naphtha. This also implies that the relative price is constant between gas oil and kerosene, but not between these products and naphtha. Given that the crude oil price seems to determine these prices, this also provides an example of supply driven market integration.

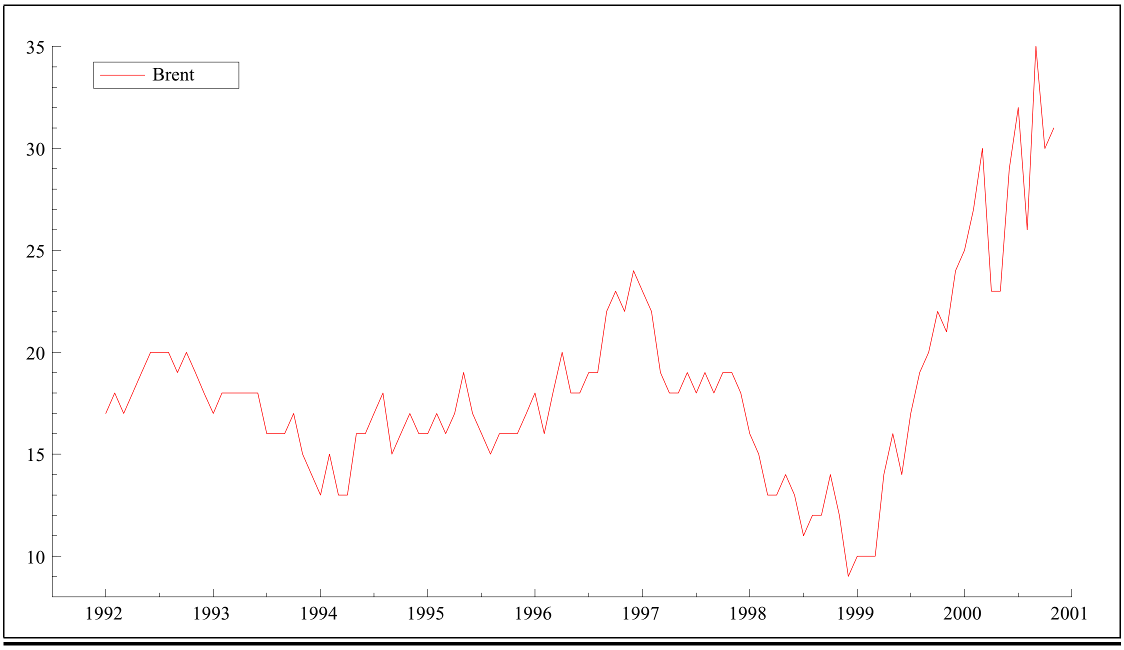

Figure 1: Crude (Brent) prices US$ per barrel, January 1992-November 2000

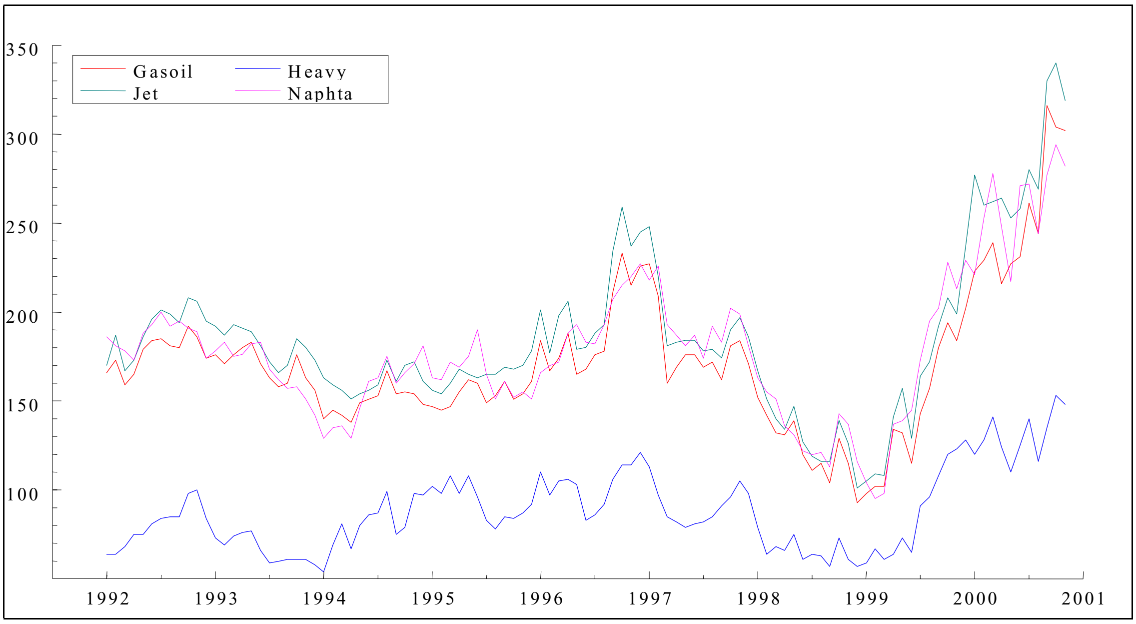

Figure 2: Oil Product Prices US$ per metric ton, January 1992-November 2000

Table 1. Stylised Facts, monthly crude and oil product prices 1992-2000,
Crude: USD/bbl, Refined products: USD/ton

	Mean Price levels	Coefficient of Variation Price levels (%)
Brent	18.1	25.8
Gas Oil	170.6	23.6
Kerosene	184.9	24.5
Naphtha	178.83	22.3
Heavy Fuel Oil	88.4	25.6

Table 2: ADF tests results

Variable	Price Levels		First Differences	
	with constant	with trend	with constant	with trend
Brent	-2.117	-2.081	-4.39**	-4.641**
Gas Oil	-2.191	-1.951	-4.004**	-4.295**
Heavy Fuel Oil	-1.334	-1.841	-4.583**	-4.628**
Kerosene	-2.261	-2.073	-3.917**	-4.165**
Naphtha	-2.304	-2.296	-4.426**	-4.597**

** indicates significant at 1% level and * significance at 5 % level
Critical values prices levels with constant are: 5%=-2.82; 1%=-3.499,
with constant and trend: 5%=-3.457; 1%= -4.056.
Critical values for first differences with constant are: 5%=-2.89; 1%=-3.496
and constant and trend: 5%= -3.454; 1%=-4.051.

Table 3: Misspecification test in the system

	Brent	Gas Oil	Fuel Oil	Kerosene	Naphtha
Autocorrelation	1.0968	1.1909	0.71277	1.341	1.8767
	(0.1429)	(0.3051)	(0.7345)	(0.2139)	(0.0508)
Normality	5.3125	3.6705	4.1364	3.6753	1.623
	(0.0702)	(0.1596)	(0.1264)	(0.1592)	(0.442)

p-values in parenthesis indicates significance at 5% level

Table 4: Multivariate Johansen Test for Crude and Oil Product Prices

H_0:rank=p	Max test	critical value at 5%	Trace test	critical value at 5%
p = = 0	47.99**	34.4	116.5**	76.1
p<=1	29.48*	28.1	68.54**	53.1
p<=2	23.83*	22.0	39.05*	34.9
p<=3	12.4	15.7	15.22	20.0
p<=4	2.824	9.2	2.824	9.2

** indicates significance at 1% level and * at a 5% critical level

Table 5. Bivariate Johansen tests for cointegration

Variables	H_0:rank = p	Max test	Trace test
Brent – Gas Oil	P= =0	18.43*	21.16*
	P<=1	2.725	2.567
Brent – Heavy Fuel Oil	P= =0	12.46	13.82
	P<=1	1.358	1.358
Brent - Naptha	P= =0	30.19**	31.3**
	P<=1	1.107	1.107
Brent - Kerosene	P= =0	19.62*	21.13*
	P<=1	1.511	1.511
Gas Oil – Heavy Fuel Oil	P= =0	10.73	12.5
	P<=1	1.766	1.766
Gas Oil - Naphtha	P= =0	16.13*	17.98
	P<=1	1.855	1.855
Gas Oil - Kerosene	P= =0	22.13**	23.51*
	P<=1	1.382	1.382
Heavy Fuel Oil - Naphtha	P= =0	14.07	16.15
	P<=1	2.077	2.077
Heavy Fuel Oil - Kerosene	P= =0	9.829	11.42
	P<=1	1.592	1.592
Naphtha - Kerosene	P= =0	14.68	16.21
	P<=1	1.534	1.534

**indicates significance at 1 % level and * indicates significance at a 5% level
critical values for the trace tests are 20. 0 and 9.2 respectivly at a 5% level and
critical values for the max test are 15.7 and 9.2

Table 6: Misspecification test of the reduced system

	Brent	Gas Oil	Kerosene	Naphtha
Autocorrelation	1.6761	1.2773	1.3781	1.9796*
	(0.0882)	(0.2487)	(0.1941)	(0.0371)
Normality	5.6933	4.5695	4.6968	1.6549
	(0.058)	(0.1018)	(0.0955)	(0.4372)

p-values in parenthesis, * indicates significance at 5% level

Table 7. Multivariate tests for Crude and Oil Products (excluding Heavy Fuel Oil)

H_0:rank= =p	Max test	Critical value at 5%	Trace test	Critical value at 5%
p= =0	49.74**	28.1	98.14**	53.1
p<=1	27.67**	22.0	48.4**	34.9
p<=2	17.68*	15.7	20.73*	20
p<=3	3.057	9.2	3.057	9.2

**indicates significance at 1% level, * significance at a 5% level

Table 8. Weak Exogeneity Tests

Variable	Test Statistic	*p*- value
Crude Oil (Brent)	6.3448	0.1334
Gas Oil	16.229**	0.0010
Kerosene	11.513**	0.0093
Naphtha	25.411**	0.0000

**indicates significance at 1% and * significance at 5% level

Table 9. Price proportionality

Variables	LOP	*p*-value
Brent – Gas Oil	0.152332	0.6963
Brent – Naptha	10.593**	0.0011
Brent - Kerosene	0.015585	0.9006

**indicates significance at 1 % level and * indicates significance at a 5% level

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