



UNIVERSITÀ DEGLI STUDI ROMA TRE
DIPARTIMENTO DI ECONOMIA

**NEW EVIDENCE ON THE RELATIONSHIP BETWEEN CRUDE
OIL AND PETROLEUM PRODUCT PRICES**

Mario Denni Geoffrey Frewer

Working Paper n° 61, 2006



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New Evidence on the Relationship Between Crude Oil and Petroleum Product Prices

Mario Denni* Geoffrey Frewer**

November 2005

Abstract

The present study aims at providing new evidence on the price relationships between crude oil and petroleum products. We employ single-equation error correction models (ECM) in which both changes in crude oil price and deviations from the long-run equilibrium are used to explain product price dynamics. A GARCH structure is applied to models' residuals to account for the time-varying volatility. Our key piece of innovation is the introduction of refining margin effects to the analysis of the asymmetric products price movements. Results suggest that the overall balance in the refinery sector plays an important part in the adjustment to crude price shocks.

JEL classification: E32; C22; D40; Q40

Keywords: Oil prices; Market integration; Cointegration; Error correction models; GARCH models; Asymmetric adjustment.

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1 Introduction

Significant price volatility in global energy markets is of interest to investors and policy-makers, given the impact that unanticipated movements in energy prices can have on project profitability and macroeconomic performance. Despite recent attempts by oil-producing nations to introduce some stability into crude oil price, there continues to be difficulty in anticipating its movements and the implications for economic activity and inflation. Moreover, different scenarios for crude oil price are likely to be characterized by different levels of and ratios among refined product prices, given that crude is the major input in the refining process. In many activities these product price differentials turn out to have more relevance than the general level of energy prices in assessing the potential profitability of a project. For example, this is primarily the case for integrated companies operating in the oil industry, which both extract and refine crude oil. In such situations, changes in the overall level of energy prices may not contain useful information for project risk management since oil price relationships are the key determinant of profit.

Relative demand for petroleum products varies over time. So do relative prices. Nevertheless, some market integration leads to the existence of stable long-lasting relationship among oil product prices. This is due to the possibility for refiners to choose the optimal output mix in response to variations in the economic situation by changing the relative amounts of different products that can be distillate from a barrel of crude, that is their relative supply. And where, especially in the short-term, physical and technological constraints would reduce this output flexibility, stock adjustments can re-establish refiners' ability of meeting relative demand changes leaving

relative prices almost unchanged. As a result, there are reasons to believe that a fairly stable equilibrium holds between crude and petroleum product prices, and consequently, among product prices.

The present study aims at exploring the existence and the behaviour of such price relationships. We adopt a single-equation framework based on the assumption of weak exogeneity of crude oil price. The presence of cointegration between crude and oil product prices suggests the use of an error correction model (ECM thereafter) in order to account for both variations in crude oil price and deviations from long-run equilibrium in predicting product price dynamics. Moreover both visual inspection and statistical tests provide evidence that oil product price series exhibit variance persistence and are characterized by many extreme values. Then we employ a GARCH structure over the error terms. As to the short-run dynamics of the series we divide our exercise in two steps. Firstly, we explore the two conventional, widely tested, sources of asymmetry: the one in the adjustment to long-run disequilibria and that relative to the direction of the Brent price change. Secondly, the usual asymmetric error correction model will be modified to introduce refining margin effects to the analysis. Since refining adds value to crude oil, this plays a central role in the oil business. Our intuition is that the composition of refinery throughput and the relative product prices respond to changes in crude oil price in different ways depending on the last period performance (in terms of the refining margin) of the refining sector. We will adjust our error correction model in order to be able to distinguish between two types of asymmetries: the first refers to the direction of crude price changes, the second one instead is related to the sign of last period's refining margin. Should this setting hold, the result would be twofold. First, it would confirm the existence of an asymmetric response of all product's

prices to crude price changes. Second, it would suggest that taking into account recent path of the refining margin may be of some help in our attempt to understand and predict product price movements and best direct economic policy tools. Our findings show that every coefficient is statistically significant and interestingly a substantial, economic meaningful difference between all them is in fact found. Such an outcome leads us to conclude for the presence of a double asymmetry driving the price patterns of petroleum products. Statistical tests performed to establish whether the divergences among coefficients are statistically significant attest the robustness of the outcome.

The rest of the paper is organized as follows. Next section 2 provides a review of the recent literature on these topics followed by a description of the price series used (section 3). A first investigation of these data and of their possible co-movements through some descriptive statistics and a correlation analysis comes after in section 3.1. Section 4 contains the analysis of the econometric aspects of the model. Section 4.4 shows and discusses first results and tests their robustness. The role of the refining margin effects in explaining the asymmetric dynamics is investigated in section 5. Section 6 concludes.

2 Literature Review

Surprisingly, just a couple of papers deal with the price relationship between crude and refinery products and the patterns of oil product price differentials. Indeed the majority of the related literature pay much more attention to the gasoline market. Gjlberg and Johnsen (1999) analyses co-movements between monthly prices (observed on the Northwest European market) of

crude oil (Brent) and six oil products (Gasoline, Naphtha, Jet Fuel, Gas Oil, Light Fuel Oil 1%, and Heavy Fuel Oil 3.5%) for the period 1992 – 1998. They follow a pairwise approach taking crude price as the exogenous variable and using co-integration and error correction techniques. Technically, they specify and estimate a short-run dynamics and then calculate the long-run solution of the process resulting from the estimated short-run model. Authors put some emphasis on the lack of sensitivity of heavier products (1% and 3.5% fuel oils) to crude changes. They also state that the error correction mechanism is faster in gasoline and naphtha (in two-month time) than in jet fuel and gasoil (it takes two more months). Finally, they examine the price spreads finding again that the correction process works faster for the lighter products.

A multivariate framework is used by Asche *et al.* (2003). Their analysis is restricted to the relationship between monthly prices of Brent and four oil products (Naphtha, Gas Oil, Jet Fuel and Heavy Fuel Oil) traded on the Rotterdam market in the period 1992 – 2000. Their results indicate that heavy fuel oil 3.5% is not cointegrated with any of the other prices, suggesting that the price for this product is independent of crude oil price, whereas all other prices appear to be cointegrated with crude oil price. In addition, with the exception of naphtha and kerosene, product prices seem to be also cointegrated with each other, implying that products markets are integrated and their price series share the same stochastic trend. As pointed out by the same authors, this link provides evidence of the output mix adjustments made by refiners to respond to changes in the relative product demand. Finally, they state, completely in line with our results, 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.” (p.298)

As far as asymmetric price movements are concerned, despite the enormous effort, the specific literature is yet far to reach a generally accepted conclusion.¹ First of all, it should be noted that the empirical studies dealing with this topic greatly differ in data frequency, sample period, choice of the input price and of the model specification, which may account for the different conclusions on price asymmetry they reach. However, some common features can be pointed out. The price setting behaviour in the U.S. and U.K. gasoline market in a period usually spanning from early 80s to late 90s is explored. The frequency of the data is typically either weekly or monthly, although sometimes biweekly data are also employed. As a rule, a single stage analysis relating directly the price of crude oil to the pump price is set up. Sometimes, the oil industry is instead broken down into two stages: the production and the distribution chain. The former framework involves crude price and spot gasoline price, whereas the latter wholesale and retail gasoline prices. Differences can be also found about the econometric tool employed. While most research has been carried out by using the usual, but inappropriate with cointegrated series, Vector Autoregression (VAR) anal-

¹Asymmetric price movement is cause of concern not only in the oil industry. Many studies investigate price asymmetries in various markets (including bank deposits and agricultural products). Above all, Peltzman (2000) uses large samples of diverse products: 77 consumer and 165 producer goods. He concludes for the pervasiveness of prices rising faster than they fall. On average, the immediate effect on prices of an increase in input costs was at least twice as large as the effect of a decline in input costs. Moreover, the differential was sustained for at least five to eight months.

ysis, just few papers make use of the unit-root and cointegration technique, modeling asymmetric price effects both in the short-run and long-run. As said, the resulting general picture is confused.

In regard to the U.K. gasoline market, Bacon (1991) and Manning (1991) report partially conflicting results. Using semi-monthly data from 1982 to 1989 and a quadratic quantity adjustment function, Bacon reports evidence of a faster and more concentrated response of the retail price to spot price increases. The latter instead exploiting monthly data on crude oil prices and retail prices from an even earlier period (1973 – 1988), concludes that price asymmetry, though present, is relatively short-lived, being any asymmetry virtually absent after four months. Reilly and Witt (1998) revisit the evidence of these authors with monthly data for 1982 – 1995 and emphasize the role of the dollar-pound exchange rate and the potential asymmetries associated with it, in addition to those of crude oil prices. A restricted ECM is estimated which allows only for short-run asymmetry. The hypothesis of a symmetric response by petrol retailers to crude price rises and falls is rejected by the data, and so is for changes in the exchange rate.

Shifting attention to the U.S., even less uniformity appears. Borenstein and Shepard (1996) estimate an asymmetric partial adjustment model and a VAR model on weekly observations at 188 terminals for the period 1986 – 1992 finding that terminal prices respond asymmetrically to changes in crude oil price. Borenstein et al. (1997) estimate a VAR model for the gasoline market using semi-monthly data over the period 1986 – 1990. Their results also indicate that retail prices adjust more quickly to crude oil price increases than to decreases. In the next stage, there appears to be no asymmetry between spot and wholesale prices. Finally, retail prices show asymmetry in responding to wholesale price changes, possibly indicating short

run market power among retailers. In sharp contrast, opposite conclusions can be drawn from the very first works by Karrenbrock (1991) and Shin (1994). Karrenbrock employs 1983 – 1990 monthly data to study the empirical relationship between wholesale and (after tax) retail gasoline prices. The author uses a distributed lags model to find that the length of time in which a wholesale price increase is fully reflected in the retail gasoline price is the same as that of a wholesale price decrease for premium and unleaded regular gasoline. The author concludes, contrary to the popular belief that consumers do not benefit from wholesale gasoline price decreases, these are eventually passed along to consumers as fully as are wholesale gasoline price increases. Similarly in his investigation of the U.S. market, Shin (1994) relates the average wholesale price of oil products to the price of oil. He uses monthly data for the period 1986 – 1992 and regresses average wholesale price changes on positive and negative oil price changes and shows no evidence of short-run asymmetric effects. In line with them is also a more recent paper by Balke *et al.* (1998) who extend the work of Borenstein *et al.* (1997) by using two different model specifications with weekly data from 1987 through 1997. In particular the authors use a distributed lags model in price levels with asymmetric effects and an ECM representation which allows for both long-run and short-run asymmetries. The authors do not obtain unambiguous evidence concerning asymmetry, which is found to be weak in the specification in levels and moderate and persistent in the ECM. Lastly, Godby *et al.* (2000) apply a threshold error correction model to test for asymmetric pricing in the Canadian (both premium and regular) gasoline market since they state that the asymmetric ECM specifications used in previous studies are misspecified if price asymmetries are triggered by a minimum absolute increase in crude cost. The analysis is based on weekly

data for thirteen cities between 1990 and 1996. On this basis the authors fail to find evidence of asymmetric pricing behavior.

Finally, three recent papers look at the experience of other countries. Asplund *et al.* (2000) use monthly data during 1980 – 1996 to explore the Swedish gasoline market. They find support for the hypothesis that retail prices are stickier downwards than upwards in response to cost shocks. Kirchgässner and Kübler (1992) look at West Germany for the period 1972–1989 using monthly data. The authors consider the response of both consumer and producer led gasoline prices to the spot price on the Rotterdam market; they distinguish two periods, before and after January 1980. By adopting a very rigorous methodology (tests for unit roots, Granger causality, cointegration, and structural breaks are performed and when cointegration can not be rejected, both symmetric and asymmetric ECMs are fitted) they show that, while long-run reactions are not significantly different for the 1970s and the 1980s, there is considerable asymmetry in the former period but not in the latter in the short-run adjustment processes. In particular, reductions in the Rotterdam prices are transferred faster to German markets than increases. Finally, Galeotti *et al.* (2002) carry out an international comparison of gasoline market. They examine the issue of asymmetries in the transmission of shocks to crude oil prices into the retail price of gasoline in five major European countries (Italy, Spain, France, Germany and the U.K.). The data are monthly and in general range from 1985 and 2000 and are used in the estimation of an ECM specification which allows for asymmetries both in the long-run and short-run components. The authors adopt a two-stage modeling (refinery and distribution stages) and find that widespread differences in the adjustment speeds and in the short-run elasticities characterize both stages.

3 The Data

Our analysis is based on weekly price series of crude oil and six oil products in the period from January 1990 to September 2005. The focus is on the Northwest European market. The crude oil price is dated Brent and product prices are those set in the Rotterdam market (the name used to indicate the large refining and storage complex in the area between Antwerp, Rotterdam, and Amsterdam) for naphtha, gasoline premium, gasoil, kerosene, light fuel oil (1%), and heavy fuel oil (3.5%). Rotterdam prices are generally regarded as the “base” level to price oil products in trade and in internal company transfer throughout Northern Europe. All product prices are in U.S.\$ per metric ton, whilst Brent price is in U.S.\$ per barrel. All data are either provided by Platt’s, an energy industry information and service agency or taken from the Oil Market Report of the International Energy Agency.²

3.1 Descriptive Statistics and Correlations

Table 1 shows some descriptive statistics of the series over the period covered by our analysis (1990 – 2005). Gasoline premium and kerosene are yielding the highest prices, whereas as expected heavier products show the lowest values. Although mean prices differ widely, the coefficients of variations (a measure of the deviation of a variable from its mean) are pretty similar one another. The price level variability is around 40% of the corresponding mean. Visual inspection of graphs in figure 1 highlights changes over time in the variability of the series, as well as in their means. Apart from the exceptionally high value in the early 90’s (due to the first Gulf war), all price series show relatively smooth dynamics, with uniformly low levels and

²For more information about the data used in this study see Appendix A.

volatilities till 1997. Since 1998 instead the series have had markedly higher average levels and risen together with considerable variation. This may be due to many different events that have occurred during the last eight years, the most relevant being the Asian Crisis,³ which reduced the demand for oil immediately by more than half a million barrels a day and cumulatively by more than a million barrel a day, leading to the collapse of oil prices in 1998, the attack to the American Twin Towers in September 11th and the second Gulf war (in 2003).⁴

In tables 2 and 3 we report the simple partial correlation of price levels and percent price changes respectively. As already noted in Gjolberg and Johnsen (1999), the most striking result is not the strong co-movements between crude and oil product price levels as well as across the different products, but instead the relatively high figures of percent price change correlations. As usual, the strongest tie is found between products coming from the same part of the crude barrel, like gasoil and kerosene, since an increase in the output of one product can not be obtained without decreasing the amount of the other. Again not surprisingly, this link becomes less evident as heavier product are concerned. However, with respect to the previous studies, our results indicate a tight market integration also for the “bottom end” oil products. This can be consider as a first signal, to be confirmed later on, that in contrast with the choice made in Gjolberg and

³For an analysis of the impact of the Asian crisis on the behaviour of US and international petroleum prices, see Hammoudeh and Li (2004).

⁴Even if we do not report the values, it is interesting to note that these facts have affected all the prices’ distributions as shown by the post-1998 values of kurtosis and skewness that are much lower than they were before 1998. This corresponds to distributions less peaked and with much less flat right tails.

Johnsen (1999) and Asche *et al.* (2003),⁵ fuel oil dynamics are now to be considered jointly with those of crude and the other oil products.

4 Econometric Results

In the following sections we implement the cointegration technique. We follow the procedure indicated by Engle and Granger (1987), that is made up of different steps. In the first step we pretest all variables for their order of integration. Then we determine the number, if any, of the cointegrating relations in the Brent-oil product price bivariate models. Finally, we estimate the long-run relationship and the error-correction model.

4.1 Stationarity

Cointegration necessitates the series to be integrated of the same order. We use the augmented Dickey-Fuller and the Philip-Perron tests for prices in log-levels to determine the number of unit roots in each series. Standard augmented Dickey-Fuller unit root test has great difficulty in distinguishing between integrated processes ($I(1)$) and stationary processes ($I(0)$) incorporating a jump, shift or break of some kind. As descriptive statistics in table 1 show it could be the case. This issue is the motivation for the use of the Philip-Perron unit root test. Table 4 reports the results of both tests. The null that the series has a unit root is accepted for all the prices in levels, whilst it is always rejected for their first differences. This implies that all

⁵An economic explanation offered in Asche *et al.* (2003) for this low correlation between fuel oil and the remaining oil products is that the high degree of possible substitution to other fuels in its main use (power generation) would represent an upper bound beyond which substitution would reduce price again (p.293).

price series are integrated of order one. In all cases, the tests are performed including a drift (constant) but not a time trend.⁶ The lag length is chosen according to the Schwarz Info Criterion.

4.2 Cointegrating Vectors

To determine the number of cointegrating vectors, that is of stationary linear combinations between integrated series, in a multivariate framework we follow the usual Johansen procedure. It aims at finding out the rank of the matrix associated to the lagged levels of the series (it includes the adjustment coefficients and the long-run elasticities). This amounts at testing the number of the characteristic roots that are different from zero. The statistical problem is to derive a test procedure to discriminate between the eigenvalues which are large enough to correspond stationary eigenvectors and those which are small enough to correspond to non-stationary eigenvectors. Actually the Johansen likelihood-ratio technique uses two test statistics. The first, called the trace statistics, tests the null hypothesis that the number of distinct cointegrating vectors is less than or equal to r against a general alternative. The second, known as the max-eigenvalue statistics, tests the null that the number of cointegrating vectors is r against the alternative of $r + 1$. In a bivariate framework as the one employed here we should be able to discriminate between the following alternatives: no, one, or two cointegrating vectors. The first case would correspond to prices being integrated of order one, $I(1)$, but with no stationary cointegrating relation between them. In the second case there is one stationary combination whereas in the last case the series are stationary. We compute these statistics to our Brent-oil

⁶None of the results is sensitive to the inclusion of a time trend.

product price bivariate models. The results are in table 5. For all products both rank tests indicate one cointegrating equation at the 5% level of significance. This result suggests that in each bivariate system there must be one stochastic trend (that is, the two series share the same stochastic trend) and that at most one weakly exogenous variable that can be found for each price relationship.

4.3 Brent Weak Exogeneity

When investigating the relationship between prices economic theory does provide little guidance with respect to which variable should be chosen as exogenous. It is equally possible to argue that it is the demand for refinery products that is driving the crude oil price or that the relationship goes in both directions. In our single-equation framework we choose the Brent price as the right-hand side weakly exogenous variable. It means that this price is not "equilibrium adjusting". In other words, it does not move to compensate for deviations from the long-run equilibrium.⁷ Although it seems unlikely that regional changes in product demand would affect the price of crude oil (which would be determined in a world market) it is not *a priori* obvious that this assumption always holds.⁸ For such a reason, in this section we test the appropriateness of the weak exogeneity assumption of crude oil price.

We estimate a bivariate vector error correction model for all the possible Brent-product price combinations and tested the hypothesis that the

⁷Note that long-run weak exogeneity does not imply short-run exogeneity. Hence, it does not exclude the possibility that the weak exogenous Brent price is reacting in the short run to changes in the product prices in the model. Then changes in product prices may feed back to crude oil prices but these effect vanish in the long period.

⁸See Adrangi *et al.*, 2001, for a comprehensive test of the causal relationship flowing from product prices to crude oil price.

adjustment coefficient (to the long-run relationship) in the Brent equation is null. In such a case, the Brent price can be considered as exogenous for the estimation of coefficients in the single-equation models. The results in table 6 show that we can always accept the null hypothesis of a binding restriction with a high level of significance. Solely in the case of gasoline premium the Wald χ^2 -statistics is quite high. However this test also is not significant at a 5% level. Then, the direction of causality (the flow of information) in the long-run is from the Brent price (the leader) to the other product prices (the followers).

4.4 Long-Run Elasticities and Error-Correction Model

In a first stage of our analysis, the ECM is estimated in two rounds following Engle and Granger (1987). The initial step is the estimation of the long-run equation using OLS:

$$p_t = \beta_0 + \beta_1 b_t + \epsilon_t \quad (1)$$

This determines the response of each oil product price to changes in the Brent price in the long-run when the entire adjustment process is completed. Then we capture the short run dynamics allowing for asymmetry both in the adjustment path to long-run disequilibria and in the response to crude price changes:

$$\Delta p_t = \alpha_p^+ \hat{e}_{t-1} + \alpha_p^- \hat{e}_{t-1} + \sum_{i=0}^n \gamma_i^+ \Delta b_{t-i} + \sum_{i=0}^n \gamma_i^- \Delta b_{t-i} + \sum_{j=1}^m \omega_j \Delta p_{t-j} + \nu_t \quad (2)$$

where p and b stand for oil product and Brent prices, \hat{e}_{t-1} are the estimated residuals from equation 1, Δp_{t-i} and Δb_{t-i} lagged changes of the variables, and ν_t is the disturbance term. The coefficient superscripts refer to the direction of the associated series (that is whether the long-run equilibrium shock has been positive or negative and the crude price rising or falling).

Table 7 show the entire set of result. The estimates of the long-run elasticities, β_1 , are all *near* unity indicating in no case a complete, one-to-one pass-through rate from input price growth to output price growth. This implies that in the long run a 10% increase in the price of Brent results on average in a 9% increase in the spot price of oil products. It is also relevant to stress that these preliminary results provide some further evidence of the fuel oil sensitivity relative to Brent price changes. Although lower than those of lighter products, the long-run parameters associated to light and heavy fuel oil are very significant. Regarding the short-run dynamics, the results vary across products. Last week's deviation from the long-run equilibrium has significant explanatory power for current price change in all products. Except for few cases, all the adjustment speeds range between 0.07 and 0.12 implying roughly from 6 to 10 weeks to close half of the gap between actual and long-run price levels.⁹ Hardly is there any evidence of asymmetric behaviour of the series either in the long-run adjustment or in the brent price change response. We should perform the Wald test to confirm our impression. Yet the diagnostic tests at the bottom of table 7 deserve attention. The $AR(7)$ is a test of residual autocorrelation of order 1 to 7. The null of autocorrelation is rejected in three out of six cases. Moreover, the last two lines show that also the assumptions of residuals normality and homoskedasticity are strongly rejected. The $ARCH(7)$ is a test of autore-

⁹To compute the mean lag adjustment period we use the formula

$$t = \frac{\ln(1-x)}{\alpha},$$

where the numerator is the log of the proportional gap closed and the denominator the speed of adjustment coefficient estimated in the ECM equations. This formula tells us how many weeks it takes for oil product prices to revert to their equilibrium levels once a shock has caused them to diverge upward or downward.

gressive residual heteroskedasticity of order 7 whereas *Normality* denotes the usual Jarque-Bera statistics to test the residual normality. Thus, it is clear from visual inspection of figure 2 and the results of these statistics that the standard assumption underlying the regression model are clearly violated. Even though residuals fluctuate around zero and do not show high serial correlation of the first order, they exhibit serial correlation of the second order (a non-linear form of dependence), their fluctuations seem to be clustered in time (that is, there is volatility clustering or conditional heteroskedasticity), and finally there are many extreme values (distributions are leptokurtic). Assuming as is done in OLS regressions that the residuals are independently and identically distributed through periods results in loss of statistical efficiency. An appropriate extension to the above ECM model is therefore required to simultaneously accommodate for such evidence. Then we employ a GARCH structure over the residuals of the models.

The simplest GARCH(1,1) model reveals to be in most cases sufficient to provide the desired result. In few cases a richer model is instead needed. Diagnostic tests in table 8 say that heteroskedasticity is no longer a problem. There are however several outliers in the data. Then dummies are used to account for the effects of extraordinary events (*i.e.* wars, the Asian crisis) on the oil products prices in this period that violate the normality assumption. Actually, we have to understand what type of dummy we need. The main difference concerns the length of the “impulse”. A shift in the level of the variables corresponds to a permanent impulse in their differences, whereas an impulse effect in the levels corresponds to a transitory impulse in the differences. For example, a war can cause either a permanent or a transitory shift in the level of product prices. In the latter case, we would see an initial rise in the product price followed later on by a return to the previous price

level. Here, we used three types of dummies. Firstly, a step dummy, being zero up to $t = T$ and unity after that. Secondly, a “pure” impulse dummy, that is unity for $t = T$ and zero otherwise. Lastly, a “transitory” impulse dummy, taking the value of unity for $t = T$, -1 for $t = T+1$, and 0 otherwise. As to the presence of dummies in the variance equations, there we put only some step dummies. The meaning of that we think is quite clear. In some periods (the first Gulf War for instance) or from that moment on (the Asian crises in 98) the volatility of the prices series has been much higher. A good way to account for this phenomenon in the analysis is to include in the part of the model governing the conditional variance a dichotomic variable being zero up to that period and unity hereafter. The Jarque-Bera tests for normality in table 8 show that indeed the use of dummies solves the non-normality problem. Some concern still remains for the heavier products models solely.

Now we can conduct robust inference on the existence of asymmetries. The picture that emerges (the results are in table 9) is at least ambiguous. Surely there is no adjustment asymmetry. Hence product prices restore last period’s long-run disequilibria at the same pace regardless the sign of such deviations. Only the heavy fuel oil seems to follow an asymmetric path since it does not respond to negative long-run imbalance. This might be due to the fact that it is used as an alternative to other non-oil products whose prices represent a lower bound for the heavy fuel oil price. There is more evidence of the timing or pattern asymmetry (the one relative to the direction of crude price changes). However only the result of gasoil confirms the common feelings of prices being sticky. In this case indeed upward movements of the product price are significantly (but only at a 10% level) faster than downward adjustments. In the other two cases where the

coefficients equality is rejected product prices seem to respond more quickly to Brent price drops.

5 The Asymmetric Refining Margin Effects

The ambiguous results we found are in line with the weak consensus reached by the recent literature on the asymmetry issue. Indeed economists have tried to provide some competing economic explanations for the asymmetry. Comprehensive studies by Borenstein *et al.* (1997) and Brown and Yücel (2000) argue that price asymmetries might have different sources at different stages in the oil industry. Potential explanations include market power, search costs, consumer response to changing prices, inventory management, accounting practices, and refinery adjustment costs. However, to our knowledge the role of the refining margin has never directly been account for. Consequently, this last section constitutes an attempt to “fill the gap” and shed some more light on the reasons behind the asymmetry.

On theoretical grounds our intuition is broadly linked to one hypothesis (namely, *Hypothesis 1*) put forward in Borenstein *et al.* (1997). They state that “a significant positive crude price shock would trigger retail price increases, otherwise, retail margins would become negative. Retail prices need not respond immediately to a negative crude price shock” (p.325). This is based on the assumption that each firm chooses its selling price with imperfect information about the prices charged by the others. Therefore, in response to a negative cost shock, firms might keep prices at the same level as before the shock until demand conditions force a change (for example, a firm should interpret a drop in sales as a good signal of price cutting by its competitors). A similar restraint would not be present in the case of a

positive cost shock, so explaining the asymmetric product price behaviour.¹⁰ With respect to such a framework, we take a step forward by modeling a double asymmetry. Besides the usual one related to the sign of the current crude price change, we include in our error correction model a new variable whose value reflects last period's sign of the refining margin (a proxy for the trend of the profitability rate in the refining sector¹¹). This would reflect the idea that oil companies optimise their operations and have some flexibility in adjusting refinery throughput's levels and inventories, and therefore the overall balance in the sector plays a part in the adjustment to crude price shocks.

To implement and test our thesis the error-correction equation 2 takes now the following form:

$$\begin{aligned} \Delta p_t = & c + \alpha_p(p_{t-1} - \beta_0 - \beta_1 b_{t-1}) + \gamma_1 D_b D_m \Delta b_t + \gamma_2 D_b (1 - D_m) \Delta b_t + \\ & + \gamma_3 (1 - D_b) D_m \Delta b_t + \gamma_4 (1 - D_b) (1 - D_m) \Delta b_t + \sum_{i=1}^m \theta_i \Delta b_{t-i} + \\ & + \sum_{j=1}^n \omega_j \Delta p_{t-j} + \nu_t \end{aligned} \quad (3)$$

where D_b and D_m are the two dummies. D_b is 1 if the current change in Brent price is positive and 0 otherwise. Similarly, D_m is the dummy variable associated to last period's sign of the refining margin, 1 when this

¹⁰It is fair to note that according the authors, this hypothesis would have a drawback related to the lack of mechanism for firms to coordinate on a particular equilibrium among the existing ones.

¹¹Because of the existence of many other factors affecting refinery throughput levels, we are well aware that our approach might be questioned for taking the refining margin as an indicator of the opportunity to make profit in this industry. However, in our opinion it is the trend of the margin that matters much more than its absolute level in evaluating the economics of the sector.

quantity is positive and 0 when the opposite holds.¹² As such, with respect to the framework generally employed we have four (not only two) possible scenarios:

1. $D_b = 1$ and $D_m = 1$, a rise in crude price in a period of positive refining margin (γ_1);
2. $D_b = 1$ and $D_m = 0$, a margin-depressing increase in input price when refining margin is already negative (γ_2);
3. $D_b = 0$ and $D_m = 1$, a drop in Brent price that *ceteris paribus* further raises refining margin (γ_3);
4. $D_b = 0$ and $D_m = 0$, a decrease in Brent price that if not fully passed

¹²We construct the refining margin series by using crude and product price series at our disposal. The assumptions we use to compute the refining margin are taken from the Users' Guide of the International Energy Agency and a detailed description of them is presented in Appendix B. Since the refining margin is here meant to represent the monetary gain or loss associated with processing a marginal or incremental barrel of crude oil that a refiner might choose to process, it should be assessed which refinery configuration is the marginal one. Regressing the gross product worth on crude price, Bacon *et al.* (1990) concludes for the semi-complex (a configuration whose characteristics are similar to those of cracking in Appendix B) as the marginal technique because this shows a "dollar-for-dollar passing-on" (p.208). Using the same approach, we found hydroskimming to be the marginal refining process. A possible explanation for such a difference might be the fact that in the mid 80s (the period covered by Bacon *et al.*'s study) the refining industry had substantial uneconomic spare capacity that has then been shut down. As a result, capacity utilization has been increasing since then. Following the same ascending arrangement with respect to the yielded amount of gross product worth to order the different refining technologies proposed by the authors, the higher degree of capacity utilization started from the early 90s would have caused the shift from a semi-complex to a simple configuration as the marginal process.

through output prices contributes to restore a positive refining margin (74).

Since the focus is on the new potential source of asymmetric price path we use a one-step econometric technique instead of the two-step previously employed.¹³ Generally the one-equation estimation is preferred to the two-step one for two orders of reasons. First, it provides more efficient econometric estimates (since only one equation is actually estimated and not two) and the estimated long-run effects tend to be less prone to bias. Second, the two-step technique has the drawback of imposing a common dynamic factor on the regression model.¹⁴ As a result, our preferred procedure should always be the one-step one. However, to test the long-run asymmetry we need the estimated residuals from the first-step equation in the two-step procedure. Hence our initial choice to set up a two-step ECM estimation model to test the traditional sources of asymmetry. Yet leaving aside the long-run asymmetry story we do not need anymore the estimated residuals. Then our mean equation will take the form of equation 3 and the conditional variance part the GARCH structure we used above.¹⁵

Final results are reported in table 10. They suggest several remarks. Firstly, all coefficients of the refining margin effects are statistically significant at the 1% level. According to Granger and Lee (1989), the significance

¹³The one-step estimation of an ECM is also used in Borenstein *et al.*, 1997, and Gjolberg and Johnsen, 1999

¹⁴Empirical evidence has not produced much support for such common factors, rendering the two-step method non-optimal. See Campos, Ericsson, and Hendry, 1996, for a discussion of this drawback.

¹⁵As shown in Kremers, Ericsson, and Dolado, 1992, in the one-step procedure the existence of a stationary cointegrating relation between the two series can be proved by testing that the adjustment coefficient estimate is non-null (α_p in equation 3).

of individual coefficients is a necessary condition for testing for asymmetric effects. Secondly, the comparison between the four scenarios reveals that when different coefficients estimates confirm our intuition. That is the reaction of refiners to cost shocks is bigger, the worse the past trend of the economic performance of their business. The pass-through of a drop in crude price into product prices is indeed lower when the refining margin is negative so that the spread between output and input prices increases and so does the marginal profit. In the case of positive past refining margin levels, instead, a negative cost shock is rapidly reflected into lower product prices keeping fixed both the current demand and the existing, positive profit rate. This results in γ_3 greater than γ_4 . A similar mechanism works when a rise in crude price occurs. Brent price increases are likely to be quickly passed into higher product prices when the profitability rate of the industry is negative so to prevent further loss in the refinery activity return. Then γ_2 exceeds γ_1 .

As above we now proceed to test statistically such differences between coefficients estimates. Conventional Wald tests of the null hypothesis of symmetric short-run responses have been performed and results reported in table 11. The general picture is encouraging.¹⁶ The symmetry of the four

¹⁶Indeed it is important to stress that a few recent papers (Cook, Holly and Turner, 1998, 1999; Cook, 1999) have questioned the reliability of conventional tests of symmetry in the above and similar contexts. In particular, these contributions note that there is a tendency to over-reject the null hypothesis of symmetry (a biasness of this statistics in falling in the acceptance area) which can be traced to the low power of standard F-statistics. In order to overcome this unreliability of standard Wald tests of symmetry Galeotti *et al.* (2002) have bootstrapped the F statistics and have calculated rejection frequencies at the 5% significance level on the basis of 1000 replications. Reinterpreting the previous results in the light of the new findings leads the authors to draw different

coefficients is always rejected but for gasoline. It implies that the overall balance in the refinery sector does play an important part in the adjustment to crude price shocks. Moreover, gasoline, kerosene, gasoil, light fuel oil, and heavy fuel oil respond to rises in the brent price when last period's refining margin is negative. Finally, this variable seems to govern also the reaction of product prices to input shocks. Naphtha, light, and heavy fuel oil react faster to a declining Brent cost when the refinery profitability has a positive trend.

6 Concluding Remarks

In the present study, we focus our attention to the long-run spot price relationship between Brent and oil products. The econometric evidence strongly supports the hypothesis that crude and product prices are co-integrated. As a result, we have investigated how deviations from a long-run equilibrium may be used in predicting short-term product price dynamics. We conclude that past deviations from long-term equilibrium are significant in an error correction specification of short-term product price changes. The results represent valuable information for assessing project profitability, particularly in integrated oil companies for which risk management is mainly related to price differentials. To sum up, the long-run elasticities are lower as heavier products are considered. Differently from previous findings in the literature, we infer that also light and heavy fuel oils have stable relationships with Brent. The adjustment period which is necessary for a product, once shocked, to re-establish the long-run equilibrium varies across products. Light and middle distillates show faster adjustment speeds whereas

conclusions.

the convergence process takes longer for heavy products. A second result is the long-run exogeneity of Brent relative to all products. This result confirms our hypothesis on the crude-product feedback mechanism and imply that crude oil price can be taken as exogenous in the Brent-oil product price equations. Lastly, we modify our error correction model by including a double asymmetry to investigate a potential asymmetric role of the refining margin. In the new specification asymmetries arising from input price changes and those depending on the sign of last's period refining margin are distinguished. The results of the estimated coefficients confirm both the common perception of different responses of product prices to changes in the crude oil price and the presence of a refining margin effect. We are therefore tempted to conclude that “rockets and feathers” seem to dominate the price adjustment mechanism in the European oil product markets. Conventional Wald tests largely reject the symmetry hypotheses giving statistical support to our findings.

Table 1: Mean and Coefficient of Variation
(Weekly crude and oil product prices Jan 1990 - Sept 2005)

Variable	1990 – 2005		1990 – 1997		1998 – 2005	
	Mean	Coeff of Var(%)	Mean	Coeff of Var(%)	Mean	Coeff of Var(%)
Brent	23.26	41.09	19.07	20.32	27.63	41.84
Naphtha	219.51	35.60	184.24	16.48	252.49	36.97
Gasoline	248.54	42.07	191.36	12.00	290.18	41.36
Kerosene	240.53	42.51	201.65	23.66	281.06	44.70
Gasoil	216.79	42.03	181.04	20.02	250.94	44.74
Fuel Oil 1%	127.08	34.11	106.33	17.70	148.70	33.99
Fuel Oil 3.5%	108.24	39.64	87.31	21.73	130.05	38.10

Brent: U.S./bbl; refined products: U.S./metric ton.

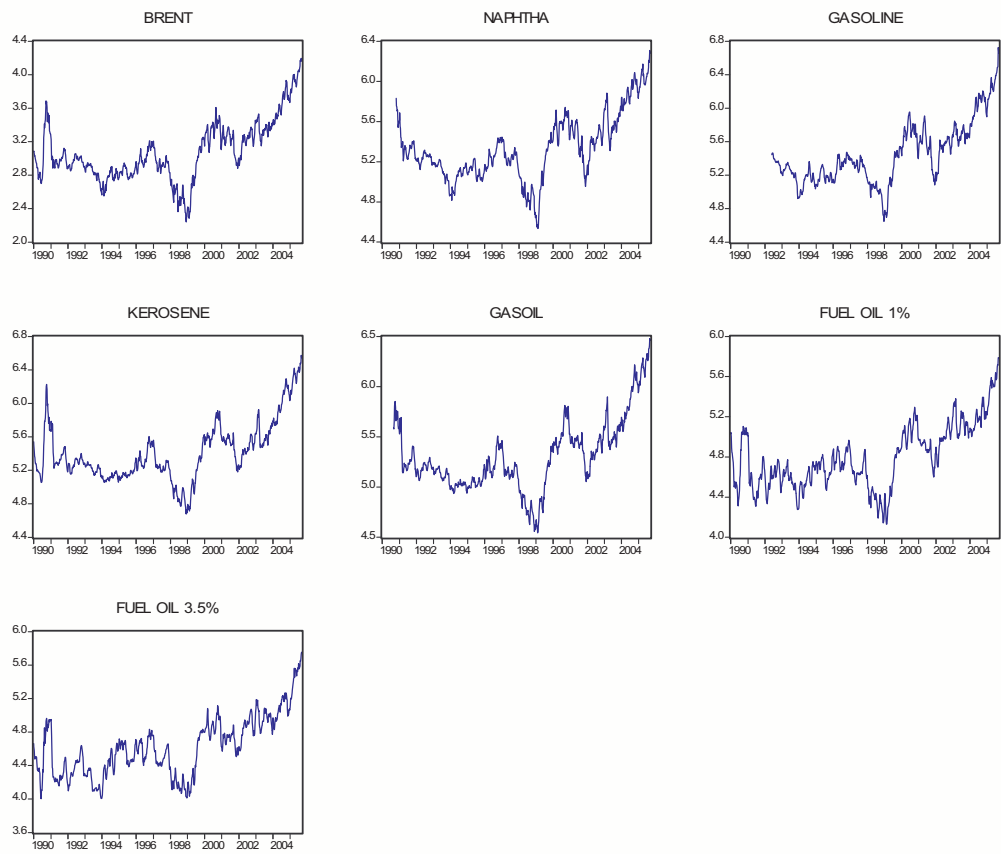


Figure 1: Time series of crude and oil log prices over the period 1990 – 2005

Table 2: Price Level Correlations
 (Weekly crude and oil product prices Jan 1990 - Sept 2005)

	Brent	Naphtha	Gasoline	Kerosene	Gasoil	Fuel Oil 1%
Naphtha	0.9766					
Gasoline	0.9749	0.9727				
Kerosene	0.9766	0.9673	0.9599			
Gasoil	0.9762	0.9653	0.9577	0.9941		
Fuel Oil 1%	0.9388	0.9149	0.9315	0.9076	0.9096	
Fuel Oil 3.5%	0.9173	0.8863	0.9081	0.8834	0.8801	0.9639

Table 3: Price Change Correlations
 (Weekly crude and oil product prices Jan 1990 - Sept 2005)

	Brent	Naphtha	Gasoline	Kerosene	Gasoil	Fuel Oil 1%
Naphtha	0.5699					
Gasoline	0.6135	0.6413				
Kerosene	0.6475	0.6066	0.5961			
Gasoil	0.6564	0.6152	0.5925	0.8948		
Fuel Oil 1%	0.4792	0.4713	0.4787	0.4773	0.4543	
Fuel Oil 3.5%	0.4771	0.4801	0.4665	0.5149	0.4798	0.6866

Table 4: Augmented Dickey-Fuller and Philip-Perron Tests Results

Variable	Augmented Dickey-Fuller		Philip-Perron	
	Levels	First Differences	Levels	First Differences
Brent	-1.16	-23.41***	-1.03	-23.25***
Naphtha	-1.41	-21.09***	-1.32	-21.02***
Gasoline	-0.51	-19.91***	-0.06	-19.81***
Kerosene	-1.04	-20.17***	-1.01	-20.17***
Gasoil	-0.71	-22.06***	-0.41	-21.69***
Fuel Oil 1%	-2.17	-18.49***	-1.65	-17.47***
Fuel Oil 3.5%	-1.69	-19.61***	-1.51	-19.63***

*** statistical significance at 1% level

Table 5: Bivariate Johansen cointegration tests for crude and oil products

H_0 : rank=P	Trace statistics	Critical value at 5%	Max-eigen statistics	Critical value at 5%
Naphtha				
None**	43.86	20.26	42.74	15.89
At most 1	1.11	9.16	1.11	9.16
Gasoline				
None**	40.46	20.26	39.47	15.89
At most 1	0.99	9.16	0.99	9.16
Kerosene				
None**	62.16	20.26	60.09	15.89
At most 1	2.07	9.16	2.07	9.16
Gasoil				
None**	62.68	20.26	61.09	15.89
At most 1	1.59	9.16	1.59	9.16
Fuel Oil 1%				
None**	40.72	20.26	38.71	15.89
At most 1	2.01	9.16	2.01	9.16
Fuel Oil 3.5%				
None**	22.12	20.26	20.05	15.89
At most 1	2.08	9.16	2.08	9.16

** statistical significance at 5% level

Table 6: Brent Weak Exogeneity Test Results

Variable	Adjustment Speed	Variable	Adjustment Speed
Brent <i>vs.</i> Naphtha	-0.01 (0.21)	Brent <i>vs.</i> Gasoil	-0.003 (0.02)
Brent <i>vs.</i> Gasoline	0.04 (2.89**)	Brent <i>vs.</i> Fuel Oil 1%	0.008 (0.29)
Brent <i>vs.</i> Kerosene	0.02 (0.55)	Brent <i>vs.</i> Fuel Oil 3.5%	0.01 (0.87)

Wald χ^2 -statistics in parentheses;

** statistical significance at 5% level

Table 7: OLS Estimation: Long-Run Elasticities and Short-Run Coefficients
(Weekly Data from January 1990 to September 2005)

	Naphtha	Gasoline	Kerosene	Gasoil	FO 1%	FO 3.5%
Proportionality Coefficient, β_0	2.62*** (121.19)	2.55*** (100.55)	2.43*** (104.59)	2.35*** (99.14)	2.26*** (68.89)	1.81*** (42.27)
Long-Run Elasticity, β_1	0.88*** (126.35)	0.94*** (115.19)	0.97*** (129.72)	0.96*** (125.78)	0.82*** (77.87)	0.91*** (65.83)
Adjustment Speed, α_p^+	-0.115*** (-4.93)	-0.071*** (-3.32)	-0.114*** (-5.99)	-0.118*** (-6.05)	-0.087*** (-4.08)	-0.093*** (-4.88)
Adjustment Speed, α_p^-	-0.121*** (-5.33)	-0.096*** (-3.89)	-0.069*** (-3.41)	-0.071*** (-3.24)	-0.044*** (-2.36)	0.001 (0.09)
Δ Brent, γ_0^+	0.472*** (12.11)	0.546*** (12.51)	0.533*** (14.59)	0.622*** (16.17)	0.278*** (5.41)	0.358*** (6.58)
Δ Brent, γ_0^-	0.464*** (12.38)	0.543*** (13.09)	0.459*** (13.86)	0.515*** (14.52)	0.464*** (10.56)	0.463*** (9.71)
Δ Dep ₋₁ , ω_1	0.266*** (9.68)	0.249*** (8.69)	0.205*** (7.95)	0.191*** (7.31)	0.447*** (14.37)	0.358*** (12.41)
Δ Dep ₋₂ , ω_2	-0.059*** (-2.19)			-0.084*** (-3.21)	-0.046 (-1.40)	
<i>Adj.R</i> ²	0.49	0.49	0.48	0.50	0.44	0.41
AR(1-7) (<i>p</i> -value)	3.12*** (0.00)	1.47 (0.17)	2.49** (0.02)	1.38 (0.21)	3.17*** (0.00)	1.05 (0.39)
ARCH(7) (<i>p</i> -value)	9.99*** (0.00)	4.15*** (0.00)	15.43*** (0.00)	23.76*** (0.00)	5.91*** (0.00)	6.18*** (0.00)
Normality (<i>p</i> -value)	50.83*** (0.00)	11.97*** (0.00)	156.53*** (0.00)	629.89*** (0.00)	17.79*** (0.00)	9.48*** (0.00)

*** statistical significance at 1% level

** statistical significance at 5% level

* statistical significance at 10% level

Unless differently specified, t-statistics are in parentheses.

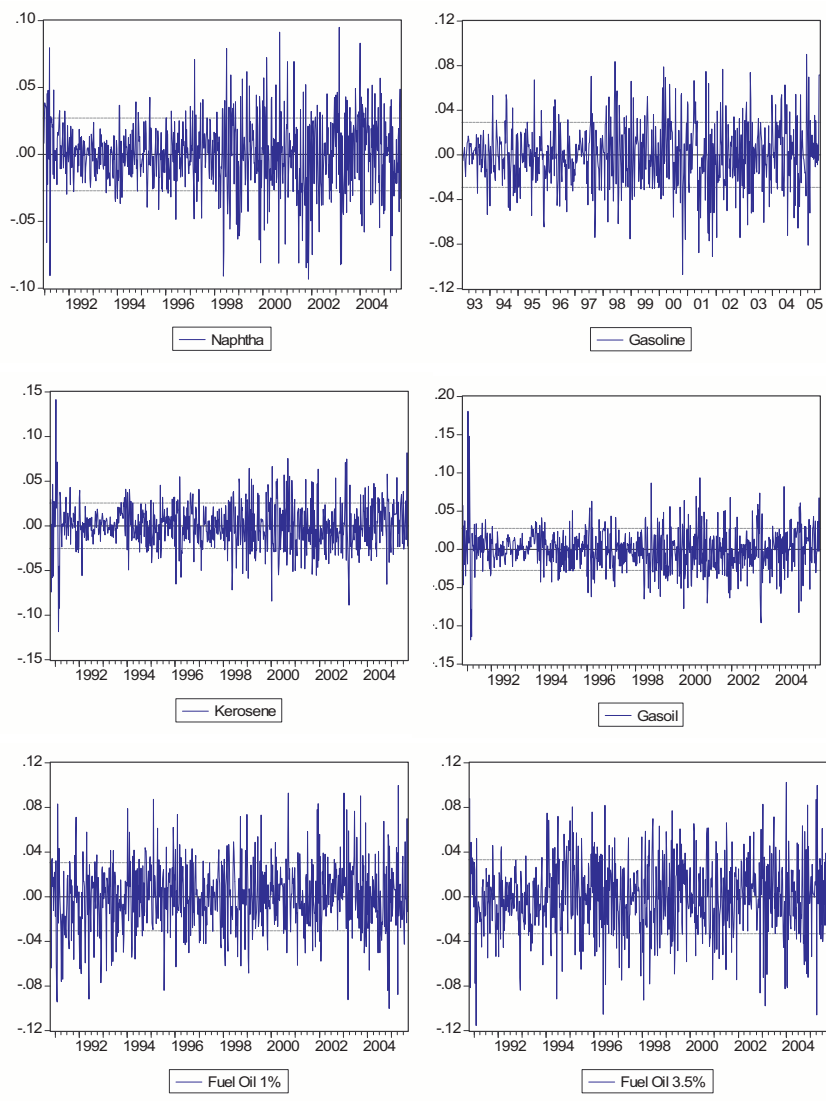


Figure 2: OLS Residuals

Table 8: GARCH Estimation Results
(Weekly Data from January 1990 to September 2005)

	Naphtha	Gasoline	Kerosene	Gasoil	FO%	FO 3.5%
Proportionality Coefficient, β_0	2.62*** (121.19)	2.55*** (100.55)	2.43*** (104.59)	2.35*** (99.14)	2.26*** (68.89)	1.81*** (42.27)
Long-Run Elasticity, β_1	0.88*** (126.35)	0.94*** (115.19)	0.97*** (129.72)	0.96*** (125.78)	0.82*** (77.87)	0.91*** (65.83)
Adjustment Speed, α_p^+	-0.128*** (-6.82)	-0.086*** (-4.61)	-0.094*** (-5.56)	-0.101*** (-5.69)	-0.072*** (-4.17)	-0.095*** (-5.42)
Adjustment Speed, α_p^-	-0.141*** (-5.79)	-0.094*** (-3.46)	-0.070*** (-3.97)	-0.078*** (-4.24)	-0.051*** (-2.96)	0.014 (0.85)
Δ Brent, γ_0^+	0.433*** (12.16)	0.516*** (14.59)	0.525*** (17.78)	0.619*** (22.48)	0.247*** (5.49)	0.316*** (6.87)
Δ Brent, γ_0^-	0.434*** (15.39)	0.509*** (15.37)	0.485*** (16.04)	0.538*** (17.66)	0.442*** (13.68)	0.475*** (15.08)
Δ Dep ₋₁ , ω_1	0.288*** (11.11)	0.291*** (10.57)	0.188*** (6.91)	0.173*** (6.51)	0.479*** (15.09)	0.387*** (13.74)
Δ Dep ₋₂ , ω_2	-0.058*** (-2.19)			-0.061*** (-2.57)	-0.088*** (-3.01)	
ARCH 1	0.149*** (3.86)	0.047*** (2.61)	0.184*** (3.65)	0.188*** (3.57)	0.238*** (4.42)	0.168*** (3.48)
ARCH 2					-0.242*** (-3.69)	
ARCH 3					0.104*** (3.25)	
ARCH 4					-0.076*** (-3.29)	
GARCH 1	0.693*** (10.57)	0.045 (0.05)	0.629*** (7.32)	0.618*** (6.96)	0.673*** (3.58)	0.586*** (5.38)
GARCH 2		0.895*** (8.73)				
$Adj.R^2$	0.51	0.49	0.48	0.50	0.44	0.40
ARCH(7) (p-value)	0.76 (0.62)	1.14 (0.33)	0.95 (0.47)	1.37 (0.21)	0.83 (0.56)	0.83 (0.56)
Normality (p-value)	1.81 (0.41)	2.99 (0.22)	2.19 (0.33)	0.66 (0.72)	7.19** (0.03)	4.90* (0.09)

*** statistical significance at 1% level

** statistical significance at 5% level

* statistical significance at 10% level

Unless differently specified, t-statistics are in parentheses.

Table 9: Wald test of Long-Run and Brent Change Asymmetric Coefficients

Null Hypothesis	Naphtha	Gasoline	Kerosene	Gasoil	Fuel Oil 1%	Fuel Oil 3.5%
<u>Long-Run Asymmetry</u>						
$\alpha_p^+ = \alpha_p^-$ (p-value)	0.14 (0.71)	0.04 (0.84)	0.79 (0.37)	0.64 (0.42)	0.61 (0.43)	13.56*** (0.00)
<u>Short-Run Asymmetry</u>						
$\gamma_1^+ = \gamma_1^-$ (p-value)	0.00 (0.98)	0.01 (0.91)	0.76 (0.38)	3.29* (0.07)	9.06*** (0.00)	5.99** (0.02)

*** statistical significance at 1% level

** statistical significance at 5% level

* statistical significance at 10% level

Table 10: GARCH Estimation: Refining Margin Effects
(Weekly Data from January 1990 to September 2005)

	Naphtha	Gasoline	Kerosene	Gasoil	FO 1%	FO 3.5%
Constant, c	0.328*** (9.53)	0.212*** (5.91)	0.158*** (5.55)	0.162*** (5.51)	0.124*** (5.31)	0.049*** (2.61)
Lagged Dependent, λ_p	-0.128*** (-9.92)	-0.085*** (-6.16)	-0.068*** (-5.94)	-0.071*** (-5.78)	-0.054*** (-5.62)	-0.029*** (-3.47)
Lagged Brent, λ_b	0.116*** (9.76)	0.080*** (6.05)	0.068*** (6.01)	0.069*** (5.73)	0.044*** (5.49)	0.029*** (3.55)
Rising Brent & Positive Margin, γ_1	0.419*** (9.48)	0.483*** (12.31)	0.452*** (14.39)	0.562*** (20.03)	0.178*** (3.18)	0.256*** (4.91)
Rising Brent & Negative Margin, γ_2	0.486*** (8.51)	0.615*** (7.84)	0.626*** (10.19)	0.761*** (12.46)	0.323*** (5.69)	0.455 (8.01)
Falling Brent & Positive Margin, γ_3	0.486*** (14.40)	0.528*** (13.03)	0.487*** (12.16)	0.553*** (14.01)	0.509*** (13.83)	0.531*** (14.95)
Falling Brent & Negative Margin, γ_4	0.331*** (6.04)	0.459*** (8.22)	0.501*** (11.09)	0.487*** (9.49)	0.329*** (5.59)	0.332*** (5.65)
ΔDep_{-1} , ω_1	0.282*** (10.52)	0.282*** (10.18)	0.178*** (6.91)	0.162*** (6.01)	0.481*** (15.68)	0.372*** (13.15)
ΔDep_{-2} , ω_2	-0.069*** (-2.65)			-0.065*** (-2.66)	-0.086*** (-2.93)	
ARCH 1	0.152*** (3.77)	0.048*** (2.66)	0.184*** (3.73)	0.191*** (3.59)	0.266*** (4.97)	0.163*** (3.36)
ARCH 2					-0.276*** (-3.81)	
ARCH 3					0.112*** (3.22)	
ARCH 4					-0.071*** (-2.98)	
GARCH 1	0.693*** (10.79)	0.049 (0.46)	0.634*** (7.60)	0.618*** (6.86)	0.699*** (3.47)	0.593*** (5.34)
GARCH 2		0.889*** (8.11)				
$Adj.R^2$	0.52	0.50	0.48	0.50	0.44	0.41
ARCH(7) (p -value)	0.98 (0.44)	1.02 (0.42)	0.97 (0.45)	1.52 (0.16)	0.77 (0.61)	0.83 (0.56)
Normality (p -value)	1.54 (0.46)	1.99 (0.37)	3.21 (0.20)	0.52 (0.77)	5.48* (0.06)	4.99* (0.08)

*** statistical significance at 1% level

** statistical significance at 5% level

* statistical significance at 10% level

Unless differently specified, t-statistics are in parentheses.

Table 11: Wald test of Refining Margin Asymmetric Coefficients

Null Hypothesis	Naphtha	Gasoline	Kerosene	Gasoil	Fuel Oil 1%	Fuel Oil 3.5%
<u>No asymmetry</u>						
$\gamma_1 = \gamma_2 = \gamma_3 = \gamma_4$ (<i>p</i> -value)	2.84** (0.04)	1.28 (0.28)	2.52** (0.05)	3.74*** (0.01)	8.61*** (0.00)	8.46*** (0.00)
<u>Brent's Rise asymmetry</u>						
$\gamma_1 = \gamma_2$ (<i>p</i> -value)	1.16 (0.28)	2.69* (0.10)	2.84** (0.00)	7.06*** (0.00)	4.49*** (0.03)	8.80*** (0.00)
<u>Brent's Drop asymmetry</u>						
$\gamma_3 = \gamma_4$ (<i>p</i> -value)	7.33*** (0.00)	1.25 (0.26)	0.06 (0.80)	1.16 (0.28)	8.57*** (0.00)	10.61*** (0.00)

*** statistical significance at 1% level

** statistical significance at 5% level

* statistical significance at 10% level

Appendix A: Data Description

Platt's weekly price series are used in this study. The complete description of each price is as follows:

Crude: Brent, Dated 10-15 days, Spot Price, Cargo Average, U.S.\$ per Barrel; Density Class: Brent Blend United Kingdom;

Naphtha: Cargoes Northwest Europe, Spot Price, CIF*, Cargo (Physical) Average**, U.S.\$ per Metric Ton; Density Class: Naphtha;

Gasoline Premium: Gasoline Premium Unleaded, Northwest Europe, Spot Price, CIF*, Cargo Average**, U.S.\$ per Metric Ton; Density Class: Unleaded Gasoline;

Kerosene: Northwest Europe, Spot Price, CIF*, Cargo Average**, U.S.\$ per Metric Ton; Density Class: Jet Kerosene;

Gas Oil: Gasoil 0.2 PCT (NO. 2), Northwest Europe, Spot Price, CIF*, Cargo Average**, U.S.\$ per Metric Ton; Density Class: Gasoil 0.2;

Light Fuel Oil: Fuel Oil 1.0 PCT (NO. 6), Northwest Europe, Spot Price, CIF*, Cargo Average**, U.S.\$ per Metric Ton; Density Class: NO.6 1.0%;

Heavy Fuel Oil: Fuel Oil 3.5 PCT (NO. 6), Northwest Europe, Spot Price, CIF*, Cargo Average**, U.S.\$ per Metric Ton; Density Class: H.S.F.O. - EUROPE 3.5%.

* CIF: Cost, Insurance, and Freight. This is a trade term requiring the seller to arrange for the carriage of goods by sea to a port of destination, and provide the buyer with the documents necessary to obtain the goods

from the carrier.

** For each series we compute the mean of cargoes high NWE and cargoes low NWE.

Appendix B: the Refining Margin Computation

In order to calculate the refining margin, we use a standard approach described in the Users' Guide (2000) released by the International Energy Agency. The refining margin is there defined as follows:

Gross Product Worth: the weighted average value of all refined product components (less an allowance for refinery fuel and loss) of a barrel of the marker, computed by multiplying the spot price of each product by its percentage share in the yield of the total barrel of crude

less Crude price: Brent FOB

less Transport costs: marginal crude freight, insurance and ocean loss, in case of an FOB crude, assuming a single voyage for an appropriately sized tanker chartered on the spot market

less Marginal refinery operating costs: defined to include only the marginal costs for chemicals, additives and catalyst

less Credit allowance representing the financial effect of the time delay between paying for crude and receiving receipts for its products, such as crude credit, crude transit and product credit, assuming a crude residence time in the refinery of five days and a product credit time of ten days.

Price quotations used to calculate the GPW are the mean of FOB cargoes high NWE and FOB cargoes low NWE for gasoline, kerosene, and 1% and 3.5% fuel oils and the mean of the CIF cargoes NWE quotations for naphtha and gasoil. Since the product price series at our disposal are in U.S.\$/Metric Ton whereas that for Brent is in U.S.\$/Barrel, we convert each product price

in U.S.\$/Barrel by using the conversion factors in table 12. The background and the assumptions behind the refining margin calculations are different for each refining centre. The resulting product yields and the additional elements used in calculating the refining margin for Rotterdam Brent reported by the International Energy Agency are summarised in table 13.

Table 12: Refined Petroleum Products Conversion Factors

Product	Barrels per Metric Ton
Naphtha	8.82
Gasoline	8.46
Jet Fuel, Kerosene-type	7.88
Distillate Fuel Oil(Gasoil)	7.46
Fuel Oil 1%	6.49

Table 13: Product Yields and Parameters for Refinery Margin Calculations
(% volume)

	Product Yields	
	Hydroskimming	Cracking
Naphtha	6.49	9.08
Gasoline	17.00	28.56
Jet Kerosene	9.39	8.88
Distillate Fuel Oil(Gasoil)	35.98	37.45
Fuel Oil 1%	28.41	14.36
Total	97.27	98.32
Refinery Fuel and Loss (% on crude)	2.73	1.68

	Parameters	
	Hydroskimming	Cracking
Marginal Operating Costs (\$/bbl)	0.30	0.40
Ocean Loss and Insurance Factor (% on crude)	0.48	0.48
Credit Factor (% on crude)	0.33	0.33

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