Petroleum products price interactions on the world markets: an econometric analysis

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This study examines the relationship between crude oil and petroleum products prices in the European, Asian and North American markets. We develop an econometric model, based on the long term equilibrium between the prices, which takes into account the changes in the oil product demand trends. We explain price behaviors by the impact of the demand trends. Because the refining industry which transforms crude into petroleum products is a joint product industry, petroleum product pricing is affected by demand trends both in terms of quality and quantity. Consequently, the long term equilibrium between prices, estimated through a cointegration approach, are affected by several structural breaks. We also develop a panel econometric model which simultaneously takes into account the relative prices of all world products towards one crude. Finally, the different results are compared to the marginal costs derived from an oil refining optimization model. This econometric modeling approach enables a better understanding of the long term equilibrium between prices of petroleum products and crude.

Keywords: Refinery industry, Petroleum product prices, Panel data, Cointegration

1. Introduction

The relationships between the crude oil price and the petroleum product prices are key factors for the analysis of the refining industry which transforms crude oil as a raw material in a set of final products for the industry or the end consumers. Nowadays, upstream activities (oil production) and downstream activities (refining industry) are frequently separated. Thus, theory on vertical integration suggests that the interest of a Producing

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National Oil Company (PNOC) in developing a downstream industry resides only on the increase of profit by integrating the downstream profit and capturing intermediary margins.

Oil refining is a joint product process that can be more or less oriented toward a set of finished products. Consequently, the downstream industry offers different industrial strategies. In order to compare these strategies, the understanding of the major oil processing industries and the formation of the prices of processed products in the different world markets is necessary to identify the opportunities for optimizing the country's revenue. The first step in increasing the value of crude oil is to process it in a refinery to produce various fuels along which some can be upgraded by downstream sectors (petrochemicals).

In addition diversification can not only be a problem of industries but also of geography. In addition, because the oil market is a worldwide market, diversification cannot be analyzed without taking into account the different regional demand patterns. Indeed while all regions are interested in crude, the consumption profiles (and even in some cases the characteristics) of products differ when dealing with refined products. To verify the assumption that integration increases profit, the evolution of the price of crude and that of petroleum products needs to be compared through time in the major consuming regions that are Europe, Asia and North America. In order to understand how the downstream integration is a way of securing revenues for a petroleum country we try to understand, through the estimation of the price coefficients towards crude oil determined by econometrics, the regional price specificities for each product.

Among the dozens of products a refinery can produce, a limited set of light products (gasoline and naphtha), middle distillates (diesel oil and jet fuel) and heavy products (heavy fuel oil- HFO) has been defined to represent the production of the refining industry. Gasoline and diesel are automotive fuels, jet fuel is used by the aviation transportation industry, HFO is used both for power generation and as a maritime fuel, whereas naphtha has a non energetic use as it is an input for the petrochemical industry.

Based on these observations we develop a time series analysis for the refining industry on the three main petroleum markets (NY: New York Spot; NWE: North West Europe; SG: Singapore Cargoes) to estimate price coefficients of the different products towards their respective feedstock. There are three criteria that define our data, nature (physical content), geography (location of market valuation) and time. Because the three markets have different yet existing demands for all the possibly produced products at different prices, we first use a cointegration econometric approach and then panel time series analyses to consider the worldwide oil market as a whole.

The prices of petroleum products are also influenced by disruptive events caused by geopolitics or environmental regulation, that can either be only short term deviations or have a durable effect and change the equilibrium like in the case of the product specification change and establishment of the EU-ETS in 2005 in the European market or the oil price crisis in 2008. Consequently, structural breaks are tested in the econometric analyses to take into account changes in the price equilibriums.

In the following section 2, we present the prices data set and we develop an economic analysis of price behavior. Section 3 is dedicated to the econometric methodology on Panel Data model. In section 4, we analyze the empirical econometric results from the cointegration model and the Panel Data model. The main economic issues are summarized in the conclusion.

2. Economic analysis and data

In order to transform the raw material that crude oil is into its end use products it is processed in refineries. A producer can choose to either sell its crude oil directly, or refine it into petroleum products.

The econometric analysis of the oil markets is carried out on the crude oil prices and the petroleum products prices - gasoline, naphtha, diesel oil, jet fuel, heavy fuel oil- on the three main worldwide markets - New-York, North West Europe, Singapore . We consider monthly data between January 2005 and February 2012 published by Platts for the price of crude oil and the five previously listed derived products (the names of the quotations are detailed in the appendix).

Subsequent changes in the specifications[1] of petroleum product specifications during the years 2000 limit the time span of the study as the industrial constraints associated with the changes modified the economics of the industry. For the same reasons, the heavy fuel oil considered is a high sulfur (3.5%) heavy fuel oil, as lower sulfur products are not significantly traded on all markets. In the econometric tests, the three different pools are named after their respective regional markets: EU for the European market, SG for the Asian market and US for the North American market.

Table 1: Descriptive statistics for refining North American prices

	US_Arab Medium	US_ Gasoline	US_Naphtha	US_Jet	US_Diesel	US_HFO
Mean	520,18	792,74	704,94	747,78	691,48	400,54
Median	496,36	775,73	680,07	692,06	643,49	390,25
Maximum	925,47	1214,74	1146,54	1301,35	1188,55	699,33
Minimum	235,65	388,31	280,97	427,19	395,88	170,58
Std. Dev.	172,34	199,93	194,14	213,07	191,04	145,76

Unit: \$/ton

A quick observation of descriptive statistics shows a clear price hierarchy towards crude (Table 1). In all three markets gasoline, naphtha, jet fuel and middle distillates ratios to crude have an above 1 coefficient, ie. they are more valued that crude oil, whereas fuel oil is less valued that crude as it is a fatal product in the joint production system. The

[1]Especially on the percentage of sulfur and polyaromatics of the automotive fuels.

coefficient of variation (ratio of standard deviation on mean) is clearly above 30% for Crude and Heavy fuel oil on all markets as they are respectively the primary resource and the fatal product. Other products have coefficients between 25% and 30% on all markets with a peak of Naphtha in Asia at 30% of variation towards its mean. This can be explained by the intense industrial activity in the region.

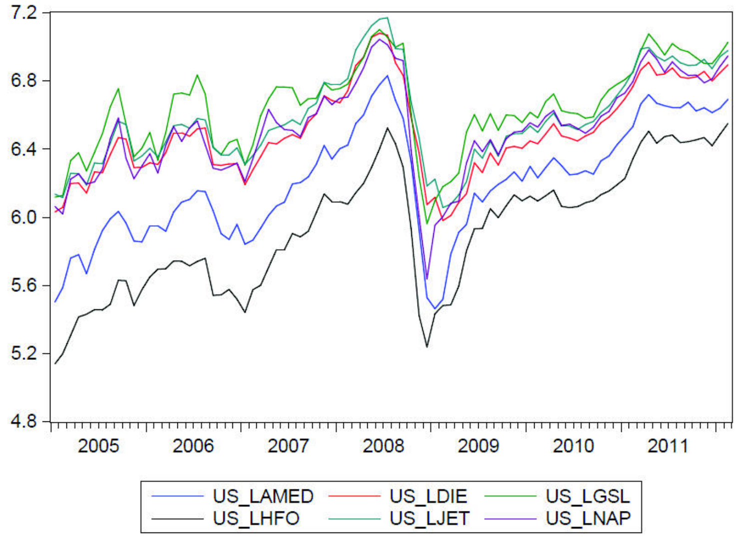

Figure 1: Values of the data in the refinery industry panels (in \$/ton)

The observation of graphical representation of the data suggests that the prices series may reveal some co-movements (Figure 1). The correlation matrix shows that all series are strongly correlated which is explained by the fact that they are joint products. The prices of petroleum products on the markets have joint processes caused by joint processes both on the supply and the demand sides.

The prices of all products have risen during the period of study until a maximum during the summer of 2008, to fall back during the second semester. The price growth dynamic started over in 2009 and continues until the end of the period with more moderate variability than in the first sub period. The oil price peak in 2008 affected the demand levels, but during the total period (2005-2011) the world demand in oil products grew by 6.7% (source: IEA Oil Market Report 2006 and 2012), at a slower pace that the price growths. The existence of this oil price crisis in the middle of the period of study supposes that the equilibriums will have to be tested for structural breaks.

3. Econometric methodology

Our goal is to test, and if they exist, to estimate the long term equilibrium between the petroleum products and the crude oil price. Because the refining industry is a joint product industry, the use of marginal costs to split the feedstock and processing costs between the products is relevant. Besides as the oil markets are considered "competitive", the petroleum product market prices should reflect these marginal costs [2]. Consequently the regression coefficients of the different products towards crude should be in accordance with their respective marginal costs.

First of all we analyze the relationships on the three separate markets (NY, NWE, SG). Classical time series unit root tests, Perron [13] tests, were conducted on the series in order to detect possible structural changes. Three different structural breaks are considered: a sudden change (denoted AO for Additive Outlier) and two distinct transitional effects (denoted IO for Innovational Outlier). The IO_1 effect stands for a transitional effect in the slope of the ADF regression, while the IO_2 effect stands for a transitional effect both in the constant and in the slope of the ADF regression.

Second, because the petroleum product markets interact, we analyze the oil market as a whole. The analysis of the market equilibriums with panel data analysis enables the taking into account of the whole world market and various structural breaks of each product (see section 4). We classically run the unit root tests on panel data- Im, Pesaran and Shin (IPS), Levin-Lin-Chu Test (LLC) , Hadri, to determine the integration order of our series. Because of these characteristics stationarity tests (unit root tests) we will use the test introduced in 1992 by Levin et al. [10] (LLC), directly inspired by the Dickey and Fuller [3] tests for time series. The Im, Pesaran and Shin (IPS) test enables the testing of integration with heterogeneous autoregressive components in addition to the intercept. The Hadri test, which is the panel variant of the KPSS tests (Kwiatkowski–Phillips–Schmidt–Shin, 1992), tests the null hypothesis that all of the individual series are stationary against the alternative of at least a single unit root in the panel. The IPS and LLC tests consider the presence of a unit root as the null hypothesis but vary because LLC considers the series are driven by a common process while IPS considers individual processes, while the Hadri (2000) test is based on the null hypothesis of the absence of a unit root[2]. When this procedure is carried out on the whole sample, difficulties come up because of the evolution of the oil markets in 2008.

Cointegration test were carried out [12, 14] before proceeding to the estimations of the long run equilibriums if cointegration exists[3]. The classical time series Gregory and Hansen [4] method is also used to test for cointegration with a regime shift in the equilibrium (constant, slope or both). We briefly describe the procedure for the panel cointegration testing and the model estimation.

The econometrics model in panel data includes a time dummy in each long run rela-

[2]These tests are considered to be the main first-generation tests for panel data. For detailed literature and comparisons of the different unit root and cointegration tests see Maddala and Wu [11], Hurlin and Mignon [6, 7], Breitung and Pesaran [1].

[3]Existing literature on testing for structural breaks in panel cointegration tests includes several papers of Westerlund and Edgerton [15], these were not implemented in this study.

tionship and is written:

$$y_{it} = \alpha_i + \sum_{j=1}^{K} \beta_{ij} z_{ijt} + \epsilon_{it} \quad (1)$$

with y_{it} the petroleum products $(i = 1, ..., N)$, z_{ijt} the explanatory variables $(j = 1, ..., K$: the corresponding crude oil and each specific time dummy variable $DU_{it}(T_B))$. Again in the regional analysis $N = 5$ and in the world petroleum analysis $N = 15$.

In the estimation of equation 1 the coefficients β_{ij} can have equal effects for each endogenous variable i, $\beta_{ij} = \beta_j$, the model is called 'within'; or have specific individual effects β_{ij}, the model is called 'between'. Pedroni [12] builds two series of tests, whether the model is 'within' of 'between', based on the same autoregressive model:

$$\hat{\epsilon''}_{it} = \rho_i \hat{\epsilon''}_{it-1} + u_{it}$$

These tests bare the same null hypothesis of no cointegration:

$$H_0 : \ \ \rho_i = 1, \forall i = 1, ..., N,$$

against the two different alternative hypotheses of common or individual coefficients for each variable of the autoregressive model:

- $H_a :$ $\rho_i = \rho < 1$, $\forall i = 1, ..., N$ for the within models,
- $H_a :$ $\rho_i < 1$, $\forall i = 1, ..., N$ for the between models.

There are four tests for the within models, three non parametric tests : panel ν-statistic, panel Phillips–Perron (PP) ρ-statistic and panel PP t-statistic and one parametric test panel ADF t-statistic. There are three tests for the between models, two non parametric tests: panel PP ρ-statistic and panel PP t-statistic and one ADF t-statistic parametric panel test. A detailed presentation of these tests can be found in Hurlin and Mignon [7] and Breitung and Pesaran [1].

Finally we carry out the cointegration tests proposed by Westerlund [14]. These tests are based on the error correction term λ_i of the short term dynamic relationships between Δy_{it} and Δx_{ijt}. In the group mean statistic test, we test the null hypothesis of no cointegration against:

- H_0^g: $\lambda_i = 0$
- H_a^g: $\lambda_i < 0$.

In the panel statistic test, we test the null hypothesis of no cointegration against:

- H_0^p: $\lambda_i = \lambda = 0$
- H_a^p: $\lambda_i = \lambda < 0$.

Significant results for cointegration lead us to estimating for both the world market and for each region a simultaneous system of equations with the presence of structural breaks for each equation. The estimation of the world panel equilibriums (on one reference crude oil) show coherent results with the univariate Engle and Granger estimations. These will be discussed in the conclusion (5).

4. Empirical results

There are market characteristics associated with each panel and that within each market or panel the different products have a specific intercept associated with the product's characteristics. The panel time series analysis offers advantages compared to classical time series analysis because of the short ranged period of the study.

4.1. Panel unit root and cointegration tests

It seems likely that given the studied series (energy prices) methods that include joint integration for all the panel are sufficient. However our panel seems to be heterogeneous concerning the individual intercepts of each product.

Table 2[4] reports the p-values of the following panel unit root tests: Levin et al. [10], Im et al. [8] and Hadri [5]. In level, results of the different tests are contradictory. The null hypothesis is not rejected for the LLC test for all three panels at a 5% significance level, but is is for the IPS test and Hadri sides with the non stationary results. Because of the mixed results we can consider that the panel is not stationary and test for the series in first difference. In first difference, the three panels are stationary and the series can be considered as integrated of order 1- I(1). We will go forward with the testing for cointegration within the panel in section 4.

Table 2: Unit Root tests on petroleum product prices. Period: 2005m1-2011m12.

		LLC	IPS	Hadri
EU Panel	Level	-0.90	-2.41***	5.41***
	1st difference	-10.02***	-8.48***	-1.78
SG Panel	Level	-0.95	-2.42***	5.79***
	1st difference	-11.23***	-9.58***	-1.77
US Panel	Level	-0.71	-2.43***	4.97***
	1st difference	-12.22***	-9.90***	-1.77

Rejection of the null hypothesis is signaled by a *** (respectively **, *) at the 1% (respectively 5%, 10%) significance level.
Probabilities are computed assuming asymptotic normality

[4] The number of lag periods was intentionally chosen as large such as suggested by Hurlin and Mignon [6] since the power is not deteriorated.

Because of the important fluctuations that occurred on the oil markets during the period studies, the Perron [13] tests point on the individual series out some changes during the past seven years (results in table 3). The significant break dates revealed by the test correspond to mid 2008: in May/June for the crude oils and in August for all of the products (results in *Level*). In difference the tests show breaks at similar dates (one to two months difference) during the year for most products. In the Singapore market the significant break date comes later than in the more mature markets for Naphtha and Diesel. The slowdown of the growth of Naphtha, a petrochemical component, was affected later on the Asian market. We can consequently consider our series are all I(1) with a structural break, we will have to consider this break in the estimation in panel data.

In order to test for cointegration between the products of each industry and their respective feedstock, we use the seven Pedroni [12] tests and the Westerlund [14] tests for panel data and the Group-mean panel cointegration tests[5], for which the null hypotheses are the absence of cointegration and the alternative ones are the presence of cointegration with a common Autoregressive (AR) coefficient for group-mean tests and individual coefficients with the panel tests.

Of the four 'within dimension' tests (results in table C.11), for which the alternative hypothesis is cointegration with common AR coefficients the null hypothesis is rejected. For the three 'between dimension' tests results side with the alternative hypothesis of cointegration with individual AR coefficients.

This result is somewhat contradictory to the more robust Westerlund test presented in table C.12 that comes to complete the analysis. On the whole period, the null hypothesis of absence of cointegration cannot be rejected. Because of the structural break analyses in the univariate study[6], the test was repeated for two sub periods[7] eliminating the oil price crisis during the second semester of 2008.

Both tests (subperiods) reject the null hypothesis of absence of cointegration for the Group_α test, concluding in a product specific cointegration relationship (results in table C.13). We will proceed with a panel estimation of the relationship taking into account this break in the equilibrium.

The tests on the different periods were also carried out on the three regional markets (for five products each) and show similar results (absence of cointegration on the whole period and significant cointegration in the sub periods).

To investigate the relationships pairwise Granger causality tests were performed between crude and the driving fuels (gasoline and diesel) as they are the ones that represent

[5]For a comparison of cointegration tests see Hurlin and Mignon [7], Breitung and Pesaran [1].

[6]In addition to the unit root testing for structural breaks, cointegration with the presence of structural breaks in the bilateral relationships of each product with crude was tested. Results of the are presented in appendix Appendix B.

[7]The two subperiods are 2005m1 to 2008m06 and 2009m1 to 2012m2.

Table 3: Individual unit root tests on refining market data with Perron test (2005m1-2011m12).

			Crude	p	Gasoline	p	Naphtha	p	jet A1	p	Diesel	p	Fuel oil	p
US	Level	IO1	2008:08**	2	2008:08***	4	2008:08***	4	2008:08***	2	2008:08	7	2008:08**	1
		IO2	2008:08*	1	2008:08***	3	2008:08***	1	2008:08**	2	2008:08	7	2008:08**	1
		AO	2011:11	7	2010:4	3	2010:3	1	2011:5	2	2011:10	7	2010:3	1
	1st difference	IO1	2008:06***	11	2008:08***	7	2008:09***	0	2008:06**	12	2008:04**	7	2008:06***	11
		IO2	2008:06**	11	2008:07**	7	2008:09***	0	2008:06*	12	2008:04**	7	2008:06***	11
		AO	2009:03	11	2009:01**	4	2008:12**	4	2011:07	4	2009:03*	4	2011:05**	0
EU	Level	IO1	2008:06***	2	2008:08***	1	2008:08***	7	2008:08**	2	2008:08**	2	2008:08**	1
		IO2	2008:06**	2	2008:08**	1	2008:08***	7	2008:08**	2	2008:08*	2	2008:08**	1
		AO	2011:02	2	2010:03	1	2010:02	1	2011:05	2	2011:05	2	2010:03	1
	1st difference	IO1	2008:06**	11	2008:08***	0	2008:10**	0	2008:06***	12	2008:04**	7	2008:06***	11
		IO2	2008:05**	4	2008:11**	0	2009:05*	0	2008:06**	12	2008:04**	7	2008:06***	11
		AO	2009:02**	4	2008:12**	5	2008:12	7	2011:09	4	2009:03	4	2011:05**	0
SG	Level	IO1	2008:06***	2	2008:08***	1	2008:08***	7	2008:08**	2	2008:08*	2	2008:08**	1
		IO2	2008:06**	2	2008:08***	1	2008:08***	7	2008:08	2	2008:08*	2	2008:08**	1
		AO	2011:02	2	2010:03	1	2010:02	1	2011:05	2	2011:05	2	2010:03	1
	1st difference	IO1	2008:06***	12	2008:10***	0	2009:03**	2	2008:06**	12	2009:01**	0	2008:06***	11
		IO2	2008:06**	12	2008:10***	0	2009:03**	2	2008:06*	12	2009:01**	0	2008:06***	11
		AO	2009:02**	4	2008:12**	4	2011:03*	2	2009:02	4	2011:11	4	2009:03	11

Rejection of the null hypothesis is signaled by a *** (respectively **, *) at the 1% (respectively 5%, 10%) significance level.
p: number of lags.

the largest volumes in the consumption profiles of all regions (approximately half of the petroleum products consumption). It appears that both in Europe and in North America, gasoline and Arab medium crude prices granger-cause each other. However for diesel oil the causality is only sideways, from crude to diesel. In the Singapore market, both gasoline and diesel Granger-cause the price of crude, which can be explained by the strong development of demand in the region over the period studied. Gasoline consumption is almost exclusively used by passenger cars, whereas diesel oil is used both by passenger cars and trucks. Consequently the respective elasticities of each product towards crude oil price increases are different as passenger cars are more sensitive than freight, which can explain the fact that gasoline prices have an effect on crude prices in the two more mature markets.

4.2. Estimating refined products cointegration to crude

Since our series are all $I(1)$, we can estimate the relationship in levels. For the regional panels a single time dummy is introduced starting in 2009 to account for the structural change in the equilibrium. The long term bilateral equilibriums of each product with its crude on the three markets show good quality of estimations as all bare above 90% explanation of the variability of the endogenous variable. This is explained both by industrial reasons and the developement of the financial markets. First the refining is a processing industry that depends for the most part on crude. Second the spot quotation of crude and products is backed by financial markets trading both fowards and futures established in the 1980s after the second oil crisis. The most important, the New York Mercantile Exchange (NYMEX), the Intercontinental Exchange(ICE) and the Singapore Mercantile Exchange (SME), have high liquidities and are strongly correlated to Spot prices (First term future prices).

For the first four light and medium products the price coefficient towards crude is well above unity and inferior for the high sulfur heavy fuel oil. Price hierarchies between products vary between regions according to regional demand specifics with gasoline being the main automotive fuel in North America and diesel in Europe. Indeed it is in the North American region that gasoline has the highest coefficient at 1.26, which is above its respective diesel coefficient 1.18. In Europe it is the opposite, the diesel multiplier towards crude is higher at 1.26 than the gasoline one at 1.20. Amongst all products jet fuel has the highest coefficients towards crude above 1.3 on all markets. Reasons for this high valuations come from the fact that the specifications for this aviation fuel are very strict, there is less choice for components of jet A1 than for other fuels, its production is thus less flexible and can be more costly. For high sulfur heavy fuel oil the price coefficient is lower in the two mature markets 0.75 (US and EU) than in Asia (SG) at 0.81 where demand is more significant.

For all equilibriums there is a significant constant in the relationship that frequently accounts for 10% of the maximum value of the series and can account for as much as 15-20%. The level of this constant gives an indication on a fixed gross margin on this product in the region and whether the price of the product is strongly attached to crude only or if there is a part of the price that is driven by a local inertia. Indeed the US Gasoline has the highest constant and heavy fuel oil has negative constants in all markets.

The coefficient of the time dummy explains the effect of the crisis that occurred. For all products but fuel oil, this effect was negative, diminishing the value of the constant associated with each equilibrium (respectively increasing the value of the constant in the case of fuel oil). The prices maintained a strong relationship with crude at a lower absolute level.

Table 4: Long term relationship between products on the European market (2005m1-2012m2).

	EU_GSL	EU_NAP	EU_JET	EU_DIE	EU_HFO
c	181.149	98.219	110.907	105.965	-18.722
	(19.677)	(13.175)	(11.728)	(13.313)	(8.388)
EU crude	1.064	1.141	1.309	1.248	0.725
	(0.039)	(0.026)	(0.023)	(0.027)	(0.017)
D0901	-24.053	-30.437	-101.309	-95.329	66.342
	(11.546)	(7.731)	(6.882)	(7.812)	(4.922)
R-squared	0.9807				

Standard deviations in parentheses

Table 5: Long term relationship between products on the Asian market (2005m1-2012m2).

	SG_GSL	SG_NAP	SG_JET	SG_DIE	SG_HFO
c	104.308	75.849	78.113	85.517	-25.430
	(15.683)	(14.438)	(10.277)	(10.802)	(6.976)
SG crude	1.188	1.160	1.301	1.255	0.820
	(0.030)	(0.028)	(0.020)	(0.021)	(0.013)
D0901	-18.047	-26.540	-90.135	-84.643	45.542
	(10.099)	(9.297)	(6.618)	(6.956)	(4.492)
R-squared	0.978				

Standard deviations in parentheses

Table 6: Long term relationship between products on the North American market (2005m1-2012m2).

	US_GSL	US_NAP	US_JET	US_DIE	US_HFO
c	223.38	139.14	124.89	131.68	-20.05
	(22.22)	(17.35)	(13.18)	(11.41)	(7.9)
US crude	1.14	1.12	1.28	1.15	0.75
	(0.04)	(0.03)	(0.03)	(0.02)	(0.02)
D0901	-58.77	-41.76	-99.02	-86.17	65.81
	(14.83)	(11.58)	(8.79)	(7.61)	(5.27)
R-squared	0.966				

Standard deviations in parentheses

The existence of these equilibriums on co-products of refining, despite the disruption by different breaks, and the presence of cointegration calls for a common analysis of the equilibriums. With these significant results, a world oil market panel of all prices on the three markets is estimated towards crude oil prices[8] during the whole period with specific dummies for each product and regions determined by the Gregory and Hansen tests (Table B.10 in appendix), denoted $DU_{it}(T_B)$ in Table 7.

Table 7: Long term relationship between products on the world markets towards EU_AMED (2005m1-2012m2).

	Gasoline			Naphtha		
	EU	US	SG	EU	US	SG
c	148.04	204.41	122.80	86.27	138.34	77.66
	(13.75)	(19.46)	(12.92)	(13.77)	(15.51)	(16.60)
crude	1.15	1.20	1.17	1.18	1.13	1.18
	(0.03)	(0.04)	(0.02)	(0.03)	(0.03)	(0.03)
$DU_{it}(T_B)$	-34.66	-65.51	-21.20	-53.68	-48.48	-44.91
	(6.85)	(9.51)	(6.03)	(7.55)	(6.84)	(9.45)

Standard deviations in parentheses

	Jet A1			Diesel		
	EU	US	SG	EU	US	SG
c	124.05	111.90	103.17	108.52	120.51	95.95
	(14.01)	(11.30)	(10.21)	(10.89)	(9.84)	(11.12)
crude	1.26	1.27	1.24	1.22	1.14	1.23
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)
$DU_{it}(T_B)$	-54.86	-74.32	-54.30	-65.41	-61.75	-58.32
	(5.82)	(5.69)	(4.81)	(5.49)	(5.07)	(5.91)

	Fuel oil		
	EU	US	SG
c	-31.67	-21.97	-10.60
	(8.01)	(7.24)	(11.27)
crude	0.77	0.77	0.84
	(0.01)	(0.01)	(0.02)
$DU_{it}(T_B)$	34.85	45.04	-
	(3.50)	(3.20)	
R-squared	0.972		

The use of the panel method enables the simultaneous estimation of the price relationships of the main products on the world markets towards a single crude marker with a high explanation of the variability of the endogenous variables (the panel estimation R-squared at 97%) and significant results for the coefficients. Indeed the estimated values of the price coefficients towards crude are in accordance with our analysis regarding the price hierarchy between products on the markets and the effect of the time dummy variable.

[8] The crude is always Arab Medium crude oil exported by Saudi Arabia. The estimation was done between the fifteen products and each of the three prices for Arab Medium and show similar results, only the estimation towards the European price is presented here.

Although the prices of products are similar on the different markets, some specificities can be revealed by the analysis and explained by local industrial or economic strategies. Of all products, jet fuel is the most valued. Between the automotive fuels diesel comes out as being the most valued in Europe and Asia, when it is gasoline that is the most valued in the US. This is explained by the fact that the share of diesel oil in the automotive fuel consumption is more important in those regions (50.5% of middle distilates and 30.1% of light distilates for Europe; 36.1% of middle distilates and 30.6% of light distilates in Asia Pacific; BP Stat 2011), and the opposite for North America (48.6% of light distilates versus 28.5% of middle distilates; BP Stat 2011). Naphtha is less valued in US than in the other regions which can be explained by the fact that their petrochemical industry is based on gas rather than on naphtha.

Given apparent similar levels for the crude coefficients of products within regions, equality tests were done by restricting identical products' coefficients to crude between regions to be equal (Chi-squared and F tests). Results in table 8, show that for all products but jet fuel the coefficients towards crude are statistically different between the three regions (the test was done with the three coefficients, it does not mean that pairs of coefficients cannot be statistically equivalent).

Table 8: Testing of crude coefficients equality for identical products between regional markets

	P value of F test
Gasolines	0.045
Naphthas	0.098
Jets	0.309
Diesels	0.000
HFOs	0.000

In addition, the estimated value of the coefficients have the same order of magnitude as the ratios between the marginal cost of the oil product and the crude oil price, obtained by a linear programming optimization model representing the world refining industry (European commission JRC report by Lantz et al. [9]).

5. Conclusion

The objective of this article is to quantify the equilibriums between the main oil products and crude prices on the main world oil markets. An empirical analysis of prices in New York, North West Europe and Singapore is developed over the last seven years during which prices were affected both by an economical crisis and changes in demand (both in terms of quality and quantity). The analyzed products are gasoline and diesel, which are automotive fuels, naphtha, which is a feedstock of the petrochemical industry, jet fuel and high sulfur heavy fuel oil.

We tested for cointegration within each regional market and revealed structural breaks in the relationship between prices of petroleum products and crude. Because the global analysis of all product prices with a single crude with an vector autoregressive estimation method presents some resolution difficulties, we used panel data methods to estimate the long term equilibrium between petroleum products and crude.

The main conclusion is that there is a significant long term relationship between crude oil prices and products on all world markets. There is a clear hierarchy between the prices of products towards crude, with all product that are more valued that crude, except for heavy fuel oil. This ranking is in accordance with the ratios provided by the comparison with a linear programming model.

This work helps us in understanding the price dynamics of products within each large consuming region of the world and between regions based on their relative pricing towards crude and consequently respective demands.

Appendix A. Statistics of the variables in each region

	EU_Arab Medium	EU_Gasoline	EU_Naphtha	EU_Jet	EU_Diesel	EU_HFO
Mean	524.53	728.58	676.55	755.44	720.15	390.90
Median	499.23	708.75	658.22	693.47	656.80	385.13
Maximum	925.41	1148.79	1091.86	1356.70	1266.40	683.65
Minimum	233.82	345.68	258.17	433.74	426.15	153.49
Std. Dev.	172.68	193.62	196.31	215.41	202.35	143.73

Unit: $/ton

	SG_Arab Medium	SG_Gasoline	SG_Naphtha	SG_Jet	SG_Diesel	SG_HFO
Mean	530,84	727,00	674,65	731,66	718,49	429,80
Median	506,29	693,57	654,90	674,91	664,97	414,19
Maximum	941,94	1178,52	1129,13	1321,52	1296,14	734,01
Minimum	248,51	344,85	261,80	403,71	397,85	187,70
Std. Dev.	168,28	201,63	200,50	210,71	205,78	148,62

Unit: $/ton

Table A.9: Descriptive statistics for European and Singapore prices

Appendix B. Classical time series cointegration tests

		EU		US		SG	
		Constant	Full Break	Constant	Full Break	Constant	Full Break
Gasoline	date	2007:10		2007:12		2008:05	
	t-stat	-5,06**	-5,24**	-5,68***	-5,63***	-5,83***	-5,83***
	lag	1	1	3	3	1	1
Naphtha	date	2008:05	2008:12	2008:09		2008:05	
	t-stat	-4,61**	-4,59	-6,57***	-6,59***	-5,72***	5,81***
	lag	1	1	0	0	1	1
Jet	date	2009:07		2009:03		2009:02	
	t-stat	-3,81	-3,83	-5,85***	-5,88***	-5,70***	-5,69***
	lag	3	3	0	0	3	3
Diesel	date	2009:05		2009:03		2009:05	
	t-stat	-5,45***	-5,46**	-5,34***	-5,39**	-6,42***	-6,43***
	lag	0	0	0	0	1	1
Fuel oil	date	2009:01		2009:02		2009:04	
	t-stat	-3,97	-4,16	-5,29***	-5,44**	-4,15	-4,20
	lag	3	3	0	0	3	3

Table B.10: Gregory and Hansen Cointegration tests on petroleum products towards their respective crudes (2005:01-2011:12). Rejection of the null hypothesis is signaled by a *** (respectively **, *) at the 1% (respectively 5%, 10%) significance level.

Appendix C. Panel data cointegration tests

	Panel cointegration tests				Group-mean cointegration tests		
	Panel ν	Panel ρ	Panel PP	Panel ADF	Group-mean ρ	Group-mean PP	Group-mean ADF
EU	0.0304	0.0002	0.0047	0.0014	0.0103	0.0154	0.0068
US	0.2572	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
SG	0.2072	0.0000	0.0009	0.0002	0.0003	0.0013	0.0014
World	0.0004	0.0000	0.0000	0.0000	0.000	0.0000	0.0000

Table C.11: Pedroni cointegration tests on panel data

	Test	Value	$p-val^a$	$p-val^b$
EU Panel	G_τ	-1.580	0.689	0.623
	G_α	-11.420	0.039	0.193
	P_τ	-3.898	0.253	0.390
	P_α	-8.526	0.015	0.227
US Panel	G_τ	-1.596	0.674	0.597
	G_α	-10.600	0.078	0.243
	P_τ	-4.724	0.067	0.177
	P_α	-12.334	0.000	0.073
SG Panel	G_τ	-1.876	0.403	0.390
	G_α	-13.701	0.004	0.100
	P_τ	-4.181	0.171	0.280
	P_α	-10.910	0.000	0.117

Table C.12: Westerlund Cointegration tests on petroleum products towards their respective crudes (2005:01-2011:12). a: p-value for a one-sided test based on normal distribution b: p-value for a one-sided test based on the bootstrapped distribution. We use 300 bootstrap replications.

	Test	Value	$p-val^a$	$p-val^b$
Jan 2005- May 2008	G_τ	-2.776	0.000	0.010
	G_α	-16.423	0.000	0.030
	P_τ	-12.745	0.000	0.000
	P_α	-19.501	0.000	0.000
Jan 2009 - Feb 2012	G_τ	-1.942	0.239	0.190
	G_α	-12.495	0.000	0.040
	P_τ	-6.440	0.201	0.260
	P_α	-10.697	0.000	0.020

Table C.13: Westerlund Cointegration tests on petroleum products towards the European crude (2005:01-2011:12). a: p-value for a one-sided test based on normal distribution b: p-value for a one-sided test based on the bootstrapped distribution. We use 300 bootstrap replications.

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