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On the relationship between forward energy prices: a panel data cointegration approach

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Abstract

The aim of this paper is to investigate the long-term relationship between the forward prices of crude oil and domestic fuel (FOD) on the period from August 2003 to April 2010. To this end, we rely on a panel data setting by considering a sample of 36 maturities for the forward prices. Using panel cointegration tests, our results show that oil and fuel prices are characterized by a strong homogeneous long-term equilibrium relationship for several maturities. Estimating a panel error correction model, we find that FOD prices are influenced by oil prices variations on both the short and the long run. The existence of a unique equilibrium model for all maturities may have important implications for financial arbitrage strategies based on energy prices relationships.

Keywords: forward energy prices, oil, domestic fuel, panel cointegration.

JEL classification: C23, Q40.

1. Introduction

The aim of this paper is to study the long-term relationship between forward prices of crude oil and domestic fuel (FOD). The empirical literature devoted to this relationship (and more generally to the relationship between oil and refined product prices), mainly relies on cointegration analysis in a time series context (see, Gjølborg and Johnsen (1999) and Asche, Gjølborg and Völker (2003)). Gjølborg and Johnsen (1999) analyze co-movements between the prices of crude oil and major refined products during the 1992-1998 period, and investigate whether deviations from a possible long-term equilibrium relationship can be used for short-term predictions and risk management. The authors conclude that crude and products spot prices are cointegrated, and rely on a vector error correction modeling. Asche et al. (2002) focus on the Northwest European market by considering a multivariate framework on the period from January 1992 to November 2000. They conclude in favor of a long-term relationship and show that the crude oil is weakly exogenous.

In this paper, we go further than these analyses based on spot price series by investigating the long-term link between forward prices of crude oil and domestic fuel for several maturities. To this end, we rely on a panel data framework including both cross-sectional and time dimensions. From a methodological viewpoint, it is well known that in small samples, traditional unit root and cointegration tests have low power against near stationary alternatives. By adding the individual dimension to the analysis, the use of panel data increases the power of

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the tests by raising the number of observations. Moreover, considering the various maturities for forward prices allow us to account for possible heterogeneity in the relationship between crude oil and domestic fuel prices. The novelty of the present study is that the cross-sectional dimension is characterized by different maturities, leading to rely on the term curve for our analysis. To our best knowledge, our paper is the first to investigate the relationships between energy prices for several terms in a panel context.

The rest of the paper is organized as follows. Section 2 presents the data and the panel unit root results. Section 3 is devoted to the empirical analysis of the link between oil and fuel forward prices, through the implementation of panel cointegration tests and estimation of error correction models. Section 4 concludes the paper.

2. Data and panel unit root tests

The data are extracted from Platt's Information Energy Agency. They concern monthly¹ forward prices of Brent (\$/b) and FOD (\$/t) for 36 maturities during the period from August 2003 to April 2010. In our panel data framework, each maturity constitutes one cross-section. Having 36 maturities, we thus have 36 different cross-sections. It should be noticed that the content of the FOD has changed on our studied period. Indeed, while the FOD was limited to content about 0.2% of sulfur since 1994, this content has been reduced to 0.1% in 2007 to preserve the atmosphere from SO_2 . To account for this change, a new series has been constructed using a concatenation procedure².

Figure 1 depicts the 12 month forward prices of Brent and FOD during the period from August 2003 to April 2010. The two series appear to be strongly correlated, and the fuel prices seem to influence Brent prices. This may be due to the absence of short-run substitutability possibilities regarding the energy fuel for heating. An increase in the demand for FOD induces a rise of fuel prices, previous to the Brent prices variations. This growth of FOD prices would lead to a rise of Brent prices, that may explain the gap between the two series.

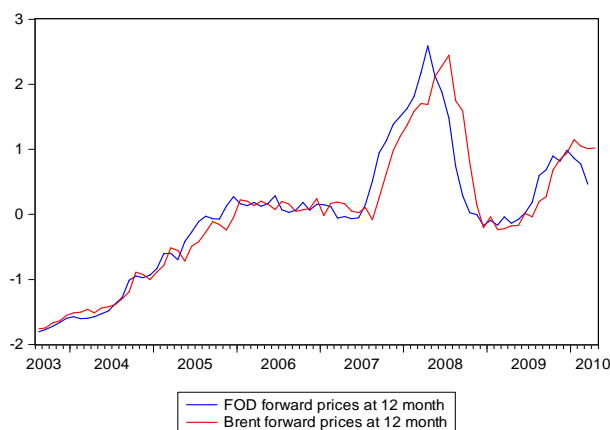


Fig. 1. 12 month forward prices of Brent and FOD, August 2003-April 2010.

¹ Series have been seasonally adjusted. Moreover, as a robustness check, we have also considered daily series. Our results (available upon request to the author) show that our conclusions are robust to the frequency.

² To assess the robustness of our concatenation procedure, we have proceeded to various tests (cointegration and stability tests). All results are available upon request to the author.

In order to investigate the long-term relationship between our two variables of interest, the first step is to test for the unit root hypothesis. As previously mentioned, it is well known that in small samples, traditional time-series unit root tests have low power against near stationary alternatives. To overcome this issue, we rely on panel data unit root tests that have the advantage of increasing the number of observations. We consider the following four tests: Levin, Lin and Chu (2002), Im, Pesaran and Shin (2003), Maddala and Wu (1999), and Choi (2001). These tests rely on Dickey-Fuller-type regressions and are based on the null hypothesis of an homogeneous unit root for all individuals ($\rho_i = 0 \forall_i$). The alternative hypotheses are different, depending on the degree of heterogeneity considered. The tests are applied to series in levels (in logarithm) and to their first-differences.

Results are reported in Table 1. They show that the two price series are non stationary in levels. Given that the null hypothesis is rejected when considered in their first differences, we can conclude that both price series are integrated of order 1 (I(1)). It is thus possible to investigate the presence of long-run relationships between Brent and FOD prices.

Table 1. Panel Unit root tests

<i>Tests</i>	<i>In logarithm⁺</i>	<i>In difference</i>
<i>H₀ : Unit Root (homogeneous AR)</i>		
<i>Levin & Lin (fodn_t)</i>	0.305(0.62)	-28.44(0.0*)
<i>Levin & Lin (brent_t)</i>	-1.862(0.03)	-39.65(0.0*)
<i>H₀ : Unit Root (heterogeneous AR under H₁)</i>		
<i>Im, Pesaran & Shin (fodn_t)</i>	3.160(0.99)	-24.16(0.0*)
<i>Im, Pesaran & Shin (brent_t)</i>	0.656(0.74)	-32.08(0.0*)
<i>ADF – Maddala & Wu (fodn_t)</i>	26.44(0.99)	682.1(0.0*)
<i>ADF – Maddala & Wu (brent_t)</i>	43.83(0.99)	952.5(0.0*)
<i>ADF – Choi Z – Stat (fodn_t)</i>	1.726(0.95)	-22.63(0.0*)
<i>ADF – Choi Z – Stat (brent_t)</i>	0.767(0.77)	-27.47(0.0*)

() p-value, *rejection of the unit root null hypothesis at the 5% significance level. *Fodn*: FOD price series, *brent*: crude oil price series.

⁺All the tests include individual and time effects.

3. Econometric results

Before proceeding to the cointegration analysis, it is relevant to assess whether the relationships between our series of interest are or not homogeneous for all maturities. To this end, we rely on the nested homogeneous Hsiao (1985)'s test. We also provide a causality analysis through the use of the Hurlin (2008)'s test.

When working within a panel data framework, investigating the homogeneity or the heterogeneity of the data generating process (existence or not of individual effects) is of crucial importance. The Hsiao-type test allows us, by successive Fisher tests, to distinguish between a (totally) homogeneous panel data framework and a (totally) heterogeneous setting by specifying the heterogeneous type. Roughly speaking, this test consists in testing the equality between coefficients of the model estimated for all cross-section units, to investigate whether the underlying model is the same in the cross-section dimension. This test is based on the following regression between the log-returns series:

$$\Delta f_{odn_{i,t}} = \alpha_i + \beta_i \Delta l_{brent_{i,t}} + \varepsilon_{i,t}$$

where, $i = 1, \dots, N$, $t = 1, \dots, T$, $\alpha_i \in \mathbb{R}$, $\varepsilon_{i,t} \sim i.i.d(0, \sigma_\varepsilon^2)$. $\Delta f_{odn_{i,t}}$ and $\Delta l_{brent_{i,t}}$ denote the log-returns series.

Results are given in Table 2 and conclude in favor of the homogeneous hypothesis: the model is the same for all maturities (from 1 to 36).

Table 2. Hsiao's homogeneity tests

Test	$H_0^1: \alpha_i = \alpha, \beta_i = \beta, \forall_i$ (homogeneity) vs $H_1^1: \alpha_i \neq \alpha, \beta_i \neq \beta, \forall_i$ (hétérogénéité)
<i>F - stats</i>	1.110
<i>p - value</i>	0.249

In this homogenous framework, we now proceed to the implementation of a causality test to investigate which series causes the other. We consider the Hurlin (2008)'s test based on the null hypothesis of no-Granger causality. Under the alternative hypothesis, a heterogeneous causality³ is considered, using the average of individual Wald statistics associated to the Granger's test of the no causality hypothesis for units $i = 1, \dots, N$. Results reported in Table 3⁴ show that there exists heterogeneous feedback causality. This bidirectional link can be explained by (i) a refining relationship between the two energies, and (ii) the absence of substitutability possibilities for FOD regarding heating at short term.

Table 3. Hurlin's no causality test

lags	$K = 1$
$H_0: \Delta f_{odn_t}$ to Δl_{brent_t} (homogeneous no causality)	
W_{NCH}	36.64
Z_{NCH}	151.2*
$H_0: \Delta l_{brent_t}$ to Δf_{odn_t} (homogeneous no causality)	
W_{NCH}	0.46
Z_{NCH}	-2.27*

* rejection of the null hypothesis at the 5% significance level; W_{NCH} converges sequentially to a standard normal distribution; Z_{NCH} is the standardized statistic.

To investigate the existence of a long-term relationship between our two price series, we consider the seven cointegration tests proposed by Pedroni (1999, 2004) and the Kao (1999)'s test. All these tests are based on the null hypothesis of no cointegration. The tests proposed by

³Under this hypothesis, there exist two subgroups of units: one with causal relationships from x to y, but not necessarily with the same data generating process; and another subgroup where there are no causal relationships from x to y.

⁴In order to assess the sensitivity of our results to the choice of the common lag-order, we compute all these statistics for several lag. Only the results corresponding to the optimal lag are reported in Table 3.

Kao examine the cross-sectional cointegration vectors in the homogeneity case, while Pedroni allows for heterogeneity under the alternative hypothesis.

For the Pedroni's tests, the following relationship is estimated:

$$lfodn_{it} = \alpha_i + \delta_i t + \beta_i lbrent_{it} + \varepsilon_{it}$$

where $i = 1, \dots, 36$ (maturities), $t = 1, \dots, T$ (time), α_i and δ_i are respectively individual and time effects.

Among the seven Pedroni's tests, four are based on the within dimension (panel cointegration tests) and three on the between dimension (group mean panel cointegration tests). The heterogeneity is introduced under the alternative hypothesis through the group mean dimension by considering $\rho_i < 1 \forall_i$ (ρ_i is obtained from the regression $\hat{\varepsilon}_{it} = \rho_i \hat{\varepsilon}_{it-1} + u_{it}$). In the within dimension, the homogeneity of the cointegration relation is only considered ($\rho_i = \rho < 1 \forall_i$).

For the Kao's test, the following relationship is considered:

$$lfodn_{it} = \alpha_i + \beta lbrent_{it} + \varepsilon_{it}$$

where $i = 1, \dots, 36$ (maturities), $t = 1, \dots, T$ (time) and α_i denote the individual effects.

Tables 4 and 5 display our results. The null hypothesis is rejected for all tests at the 5% significance level, showing that the series are cointegrated. It is thus possible to estimate the cointegration relationship.

Table 4. Pedroni's panel cointegration tests

<i>Tests</i>	<i>Statistics</i>	<i>Proba</i>
<i>H₀ : no cointegration (within dimension)</i>		
<i>Panel v – Statistic</i>	17.41	0.0*
<i>Panel rho – Statistic</i>	-13.84	0.0*
<i>Panel PP – Statistic</i>	-10.57	0.0*
<i>Panel ADF – Statistic</i>	-12.09	0.0*
<i>H₀ : no cointegration (between dimension)</i>		
<i>Group rho – Statistic</i>	-9.63	0.0*
<i>Group PP – Statistic</i>	-9.60	0.0*
<i>Group – ADF Statistic</i>	-11.15	0.0*

* rejection of the null hypothesis at the 5% significance level.
 .Regressions include individuals intercept and trend.

Table 5. Kao panel cointegration test

<i>Test</i>	<i>Statistics</i>	<i>Proba</i>
H_0 : no cointegration (homogeneity)		
<i>ADF – Test</i>	–20.68	0.000*

* rejection of the null hypothesis at the 5% significance level.

.Regressions include individual intercept only.

In a panel data setting, three main approaches exist to estimate the cointegrating relationship: (i) the Fully Modified OLS (FM-OLS, Phillips and Hansen (1990), Pedroni (1999) and Pedroni (2000)) accounting for error autocorrelation and heteroskedasticity; (ii) the Dynamic OLS (DOLS, Kao and Chiang (2000) and Mark and Sul (2003)) that consist in augmenting the cointegration relationship with lead and lagged differences of the regressors to control for the endogenous feedback effect; and (iii) the Pooled Mean Group estimator (PMG, Pesaran, Smith and Shin (1999)). Given that we have concluded in favor of the homogenous hypothesis with the application of the Hsiao (1985)'s test, we rely on the PMG estimator proposed by Pesaran et al. (1999), which is the appropriate methodology in this case. This procedure consists in estimating a panel error correction model where homogeneity across individuals is imposed for the long-run relationship, while heterogeneity is allowed in the short-run dynamics. It combines two procedures commonly used in panel data: (i) the “mean group estimate”, (totally heterogeneous) that consists in estimating separately N individuals regressions and averaging the group specific coefficients; and (ii) the pooled estimator (homogeneous), in which only the intercept is authorized to differ freely across maturities. The PMG estimator is then an “intermediate” estimator since it combines both pooling and averaging. In this sense, the main advantage of the PMG procedure is, while imposing long-run homogeneity, that it allows for short-run and error variance heterogeneity for each group of the panel.

Table 5. PMG estimates

<i>Dependant variable : lfodn_t</i>	<i>PMG</i>
<i>Error correction term</i>	– 0.413 (0.0*)
<i>Long – run coefficient</i> <i>lbrent_t</i>	0.909 (0.0*)
<i>Short – run coefficient</i> <i>Δlbrent_t</i>	0.541 (0.0*)
<i>Intercept</i> <i>(at short – run)</i>	1.063 (0.0*)
<i>Number of cross – sections</i>	36
<i>Number of observations</i>	2844
<i>Log – likelihood</i>	3285

* Significant at the 5% level.

The results of the estimation of the cointegrating relationship are reported in Table 5. The error correction term is significant and negative, and the speed of the error correction mechanism is different for the various maturities. This error correction mechanism allows short-term deviations between Brent and FOD prices to be compensated in the long-run, meaning that both series share similar long-term evolutions. The long-run and short-run elasticities (respectively 0.909 and 0.541) reveal that oil prices have more contributed to FOD prices in the long-term than in the short-term.

4. Conclusion

In this paper, we have investigated the long-term relationship between forward prices of crude oil and domestic fuel for a panel of 36 maturities. Relying on recent panel data methods, we have shown that there exists a homogenous cointegrating relationship between the two series, for all the maturities. The estimation of the corresponding panel error correction model shows however a heterogeneous error correction speed, and indicates that causality runs from oil prices to domestic fuel prices at both short and long run. On the whole, our results put forward that a unique model is sufficient to describe the relationship between the two series for all maturities. We think that these results should have important implications regarding the financial long-term arbitrage strategies based on energy price relations.

This paper may be extended to the analysis of other energy prices, such as the relationships between oil and gas, gas and electricity, *etc.* From a methodological viewpoint, it would also be interesting to account for potential structural breaks and cross-sectional dependence among individuals.

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