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Nonlinear modeling of oil and stock price dynamics: segmentation or time-varying integration?

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Abstract

In this paper, we show the usefulness of the switching transition error correction model in reproducing the bilateral linkages between oil and stock markets over the last three decades. Our findings show that while linear models fail to apprehend significant relationships between oil and stock markets, the hypothesis of financial and oil markets integration cannot be rejected using nonlinear cointegration models. More interestingly, this cointegration relationship is represented by an on-going process partially activated per regime when oil price deviations move away from their equilibrium with stock prices and exceed some threshold.

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1. Introduction

The long swings in both oil and stock prices over the recent period have motivated researchers to investigate the existing linkages between energy and equity markets. This exercise ultimately allows to gauge the impact of stock market fluctuations on oil industry and inversely. A number of studies have examined the relationships between oil price and macroeconomic variables and found significant effects of oil price changes on economic activity for several developed and emerging countries (Cunado and Perez de Garcia, 2005; Balaz and Londarev, 2006; Kilian, 2008; and Cologni and Manera, 2009). Moreover, some papers provide evidence that the link between oil and economic activity is not entirely linear, and that negative oil price shocks tend to have a larger impact on growth than positive shocks do (Hamilton, 2003; Zhang, 2008; and Lardic and Mignon, 2008).

There have been, however, relatively fewer studies questioning the oil-equity price relationships. To the extent that the value of a stock equals the discounted sum of corporate expected future cash flows which depend closely on changing macroeconomic events in response to oil shocks, the study of oil-stock relationships has numerous implications for the management of asset portfolios, especially those composed of oil-related product stocks. It is also relevant for oil firms since little is known about the reaction of oil markets toward financial shocks and crises.

For instance, the pioneering paper by Jones and Kaul (1996) investigates the short-run response of major developed stock markets (the USA, the UK, Japan and Canada) to oil price shocks by using the standard cash-flow dividend valuation model. The authors find that, for the USA and Canada, this response can be accounted for entirely by the impact of the oil shocks on cash flows. Their results for Japan and the UK were, however, inconclusive. Using an unrestricted vector autoregressive (VAR), Huang, Masulis and Stoll (1996) show a significant link between stock returns of some American oil companies and oil price changes. Nevertheless, they find no evidence of causal linkages between oil prices and market indices, such as the S&P500. By contrast, when applying an unrestricted VAR with GARCH effects to US monthly data, Sadorsky (1999) reports a significant relationship between oil price changes and aggregate stock returns in the USA. The author also points out that oil price shocks have asymmetric effects since negative oil shocks exert a greater impact on stock returns than positive oil price shocks do. In a related study, Ciner (2001) provides evidence that oil shocks affect in a nonlinear manner stock index returns in the US from using causality tests.

Studies on the oil-stock market linkages have been recently extended to the cases of major European, Asian and Latin American emerging markets. The empirical results indicate a significant short-run link between oil price changes and emerging stock markets. For example, Papapetrou (2001) shows from a standard VAR model that oil prices play an important role in explaining equity price movements in Greece. There is also evidence of significant impacts of oil prices on emerging market returns from an international multifactor arbitrage pricing theory model (Basher and Sadorsky, 2006). A nonlinear relationship between oil and equity markets for developed and emerging countries is also pointed out by Jawadi *et al.* (2010).

Overall, the previous findings are not clear-cut on the relationships between oil and stock returns. One should assign this divergence to the methodological drawbacks inherent with the linear econometric techniques used in the majority of past studies. More precisely, linear methods appear to be not powerful enough to detect asymmetries and nonlinearities that may govern the relationships between oil and stock market returns.

The objective of this article is thus to show the usefulness of the class of threshold cointegration models and particularly the Switching Transition Error Correction Model in capturing the potential of nonlinear and asymmetric links between oil and stock markets. Using monthly data for two major stock markets (USA and France) as well as the world oil price, our empirical results reveal that the considered oil-stock market pairs are nonlinearly linked each other. Furthermore, this cointegration relationship is represented by an on-going process partially activated per regime when oil price deviations move away from their equilibrium with stock prices and exceed some threshold.

The remainder of this article is organized as follows. Section 2 briefly introduces the empirical method which will be applied to our oil and stock data. Section 3 describes the data and discusses the empirical results. Section 4 concludes the paper.

2. Empirical Method

The introduction of nonlinearity in financial models is justified by the existence of market frictions such as information barriers, noise trading, transaction and information costs, and market segmentation. These imperfections may induce asymmetry, discontinuity and persistence in the oil-stock price relationships. Accordingly, a nonlinear time-varying correcting mechanism such as nonlinear cointegration models appears to be more appropriate for reproducing all types of oil-stock interactions as well as their adjustment dynamics toward their long-term equilibrium relationship.

2.1 Nonlinear cointegration models

The nonlinear cointegration is recently developed by, among others, Granger and Teräsvirta (1993), Balke and Fomby (1997), Escribanon and Pfann (1998), and Escribano and Mira (2002). It extends the linear cointegration framework of Granger (1981), Engle and Granger (1987), and Johansen (1988), which assumes either the adjustment to be nonlinear and/or the cointegration relationship to be also nonlinear.[1]

Let X_t and Y_t be two mixing processes when they are differenced *d* times, $I(d)$. If the attractor is linear, but the convergence toward the equilibrium is rather nonlinear, then X_t and Y_t are nonlinearly cointegrated. The equilibrium is defined as:

$$z_t = Y_t - \beta_0 - \beta_1 X_t \tag{1}$$

where (β_0, β_1) refers to the cointegrating vector and z_t is the disequilibrium error.

The nonlinearity is then introduced into Error Correction Models (ECMs) to develop the NECMs (Nonlinear ECMs), and a bivariate nonlinear vector ECM can be represented by

$$\begin{aligned} \Delta X_t &= \lambda_1 z_{t-1} + \sum_{i=1}^{p_1} \alpha_{1i} \Delta X_{t-i} + \sum_{j=1}^{p_2} \alpha_{2j} \Delta Y_{t-j} + \lambda_2 F(z_{t-1}) + \varepsilon_{Xt} \\ \Delta Y_t &= \lambda_1^{'} z_{t-1} + \sum_{j=1}^{p_2} \alpha^{'}_{1j} \Delta Y_{t-j} + \sum_{i=1}^{p_1} \alpha^{'}_{2i} \Delta X_{t-i} + \lambda_2^{'} F(z_{t-1}) + \varepsilon_{Yt} \end{aligned} \tag{2}$$

where $(\lambda_1, \lambda^{'}_1)$ and $(\lambda_2, \lambda^{'}_2)$ are respectively the linear and nonlinear adjustment terms for X_t and Y_t and $F(.)$ is a nonlinear transition function.

Regarding the nonlinear transition function, Escribano (2004) suggests the use of a rational polynomial function, a cubic function or the smoothing function which obviously satisfies the stability conditions. In this article, we develop a Switching Transition Error Correction Model

[1] We focus in this paper on the first type of nonlinear cointegration model (see Dufrénot and Mignon, 2002 for more details about the second type).

(STECM) by using the smoothing transition function. This model is advantageous in that it allows us to capture the possibility of regime-switching behavior in the oil-stock relationships.

2.2 The econometric specification of the STECM

The STECM belongs to the class of threshold cointegration models. Its statistical inferences were recently examined by Franses and Van Dijk (2000), and Van Dijk *et al.* (2002). This model is highly relevant for empirical finance studies owing to their ability to take into account asymmetric and discontinuous price adjustments. The STECM specifies different regimes with possibly different adjustment processes across regimes, enabling to capture temporal paths of nonlinear adjustment governed by smooth transition of regimes and to account for a gradual adjustment mechanism. It can be written as

$$\Delta y_t = \alpha_0 + \lambda_1 z_{t-1} + \sum_{i=1}^{q} \alpha_{1,i} \Delta y_{t-i} + \sum_{j=1}^{p} \alpha_{2,j} \Delta x_{t-j} + \lambda_2 z_{t-1} \times F(z_{t-d}, c, \gamma) + \varepsilon_t \quad (3)$$

where z_{t-d}, c and γ denote respectively the transition variable, the threshold parameter and the transition speed. The parameter d designates the delay parameter defining the transition variable.

The transition function may be either logistic as in Equation (4) or exponential as in Equation (5). Depending on the transition function specification, we obtain either a LSTECM or an ESTECM.

$$F(z_{t-d}, c, \gamma) = [1 + \exp\{-\gamma (z_{t-d} - c)\}]^{-1} \quad (4)$$

$$F(z_{t-d}, c, \gamma) = 1 - \exp\{-\gamma (z_{t-d} - c)^2\} \quad (5)$$

While the logistic function is often applied to capture nonlinearities in macroeconomic time series, the exponential function is rather preferred for financial data (Jawadi and Prat, 2009). In practice, the estimation of a STECM is carried out in several steps including (i) specification and linearity tests; (ii) estimation by the nonlinear least square method; and (iii) validation and misspecification tests (Van Dijk *et al.*, 2002).

3. Data and Empirical Results

3.1 Data

This study uses monthly stock returns for US and French stock markets over the period from December 1987 to March 2008. The stock market indices are from Morgan Stanley Capital International (MSCI) database, while the world oil prices (West Texas Intermediate) are obtained from the US Energy Information Administration. All data are expressed in US dollars. Returns are computed by taking the difference between the logarithms of two consecutive prices. Descriptive statistics of return series are computed, but they are not reported to conserve spaces. The results globally show that all return series display significant asymmetry and departure from normality, which is indicative of possibly nonlinear price adjustments over time.

3.2 Linear adjustment tests

We need to establish the stationarity of z_t in order to test the hypothesis of linear cointegration between oil price and stock market index for selected countries. The stationarity of z_t implies that oil and stock prices are at least linearly cointegrated and that both markets are interdependent.

Following the two-stage procedure of Engle and Granger (1987), we begin with testing the stationarity hypothesis for all studied series. Using the ADF test of Dickey and Fuller (1981) and that of Phillips and Perron (1988), we prove that all series are *I(1)*.[2] Second, we estimate the long-run relationship described by Equation (1)- X_t denotes the stock price and and Y_t designates the oil price- and test the null hypothesis of non-cointegration. The results are reported in Table 1. The hypothesis of linear cointegration is not rejected for all the countries studied at the 5% level, implying that oil and stock markets are at least linearly linked. This result is in line with that of Lardic and Mignon (2008) who also suggest significant linkages and asymmetric cointegration relationship between oil prices and GDP.

Table 1. Linear cointegration test

Test parameters	France	USA
a_0	-1.25	0.09
	(-4.33)	(0.31)
a_1	0.66	0.49
	(15.6)	(10.8)
R^2	0.50	0.32
ADF	-4.11*	-3.16*

Notes: Values between brackets are the t-ratio. * indicates that the null hypothesis of stationarity is rejected at the 5% level.

Note that oil and stock prices are, according to the ADF test results, linearly mean reverting, but any nonlinear forms of price adjustment dynamics is typically neglected by the said test since the latter seems to be not powerful enough for examining the stochastic properties of series generated by nonlinear processes (Taylor *et al*., 2001). Besides, these tests, based on linear specification, may not be able to reproduce the possible asymmetry and nonlinearity characterizing oil price dynamics. This fact justifies why nonlinear adjustment tests are more powerful and relevant in checking for the presence of nonlinearities.

3.3 Nonlinear adjustment tests

Nonlinear adjustment tests developed by Luukkonen and Saïkkonen (1988) are carried out to test the null hypothesis of linearity in Equation (2) against its nonlinear alternative in Equation (3). To do so, we first specify the LECM and determine the appropriate number of lags using the commonly used information criteria (AIC, and BIC), the Ljung-Box (1978) test for serial correlation and the autocorrelation function. These specification tests lead to retain $p = 1$ as optimal lags for all studied countries. Next, we test the linearity hypothesis by testing the null hypothesis of the LECM against its ESTECM counterpart.[3] According to Teräsvirta (1994) and Van Dijk *et al*. (2002), the linearity hypothesis is tested for several values of the delay parameter d which governs the transition variable. As we use monthly data and assume a maximum of 6-month dependence between considered variables, the plausible values of d belong to the following set: 1, 2, 3, 4, 5, and 6.

Two Lagrange Multiplier tests (LM_2 and LM_4) which follow $\chi^2[2(p+1)]$ and $\chi^2[(4(p+1)]$ distributions respectively. The obtained results in Table 2 show that the linearity is rejected for several plausible values of d. The rejection is particularly stronger for $d = 1$ for both France and the USA. Overall, the rejection of linear adjustment hypothesis implies a rejection of the hypothesis according to which the price adjustment is symmetric, linear and with constant speed. In addition,

[2] The results of unit root tests are given upon request to the corresponding author.
[3] LECM and ESTECM refer to the linear error-correction model and exponential smooth transition error-correction model respectively. The second specification allows for nonlinearities in the price adjustment process toward equilibrium.

the oil price adjustment is nonlinear and its dynamics is nonlinearly mean-reverting toward the equilibrium of the stock markets in the USA and France. Further, the acceptation of nonlinearity provides evidence of an asymmetric cointegration relationship between oil and stock prices, meaning that the linkages between these markets may be strongly activated when prices are highly increasing or decreasing.

Table 2. Linearity tests

d	**LM statistics**	**France**	**USA**
$d = 1$	LM_2	0.04*	0.01*
	LM_4	0.03	0.03
$d^* = 2$	LM_2	0.04	0.09
	LM_4	0.09	0.13
$d = 3$	LM_2	0.14	0.06
	LM_4	0.07	0.13
$d = 4$	LM_2	0.23	0.12
	LM_4	0.11	0.08
$d = 5$	LM_2	0.12	0.21
	LM_4	0.13	0.33
$d = 6$	LM_2	0.22	0.32
	LM_4	0.31	0.43

Note: * indicates the rejection of the linearity at 5%.

These stylized facts suggest that the ESTECM could be very useful to model the nonlinearities characterizing the oil price adjustment dynamics.

3.4 ESTECM estimation results

As in Michael *et al.* (1997) and Van Dijk *et al.* (2002), we begin with the estimation of the LECM using the OLS method to initialize the ESTECM parameters. The estimation of the ESTECM is then straightforward. The parameters of the exponential function γ and c are also initialized by trying various starting values. Our empirical results show several important findings. First, most estimators are statistically significant for France and the USA, and show strong evidence of nonlinear relationship between stock and oil markets. More particularly, both the current and lagged stock returns affect the oil market short-term adjustment dynamics negatively and significantly, suggesting that both markets are *a priori* integrated.

Second, the estimated transition speed is relatively high for the two above-mentioned countries. The significance of $\hat{\gamma}$ and $\hat{c}$ at conventional levels confirms the choice of the exponential function.

Third, the major parameters of the ESTECM (λ_1 and λ_2) have appropriate signs. The adjustment term in the first regime λ_1 is positive and not significant, implying that the oil price could deviate from the stock price equilibrium and stay away from it for a long period. The adjustment term in the second regime λ_2 is rather negative and strongly significant, indicating that for large deviations the oil price would be nonlinearly mean-reverting. Obviously, the oil price reacts asymmetrically to stock price shocks according to the signs of adjustment values in two different regimes. Moreover, the negativity of the sum ($\lambda_1 + \lambda_2$) suggests a nonlinear mean-reversion in the oil price for France and the USA with respect to stock market deviations. What is also important to note is that our findings confirm the presence of two regimes characterizing the oil price dynamics: a “pure chartist regime” according to which the oil price adjustment is essentially governed by its previous tendencies and a “stock market follower regime” according to which the adjustment is more activated and according to which integration between oil and stock markets is statistically very strong.

Table 3. ESTECM estimation results

Coefficients	France	USA
	ESTECM (1,1)	ESTECM (1,1)
α_0	0.012 (2.20) *	0.008 (1.57)
λ_1	0.25 (1.42)	0.18 (1.61)
α_{11}	0.22 (3.40) *	0.20 (2.92) *
α_{21}	-0.19 (-1.94) **	-0.38 (-3.12) *
λ_2	- 0.28 (-2.57) *	-0.20 (-1.99) *
γ	17.97 (2.52) *	79.63 (2.75) *
c	-0.11 (-1.83) **	0.40 * (18.58)
ADF	-11.08	-10.07
ARCH[a]	0.11	0.51
JB[b]	0.11	0.08

Note: (*) and (**) designate respectively the statistical significance at 5% and 10%. (a) and (b) designate respectively the p-values of the ARCH and normality tests. Values between parentheses are the t-ratio.

To show the existence of these regimes more explicitly, we plot the estimated transition function with respect to the transition variable in Figure 1 which enables us to explain the oil price behavior in each regime and to determine its reaction and adjustment speed after each stock market correction.

Figure 1. Transition function of oil price adjustment dynamics

France USA

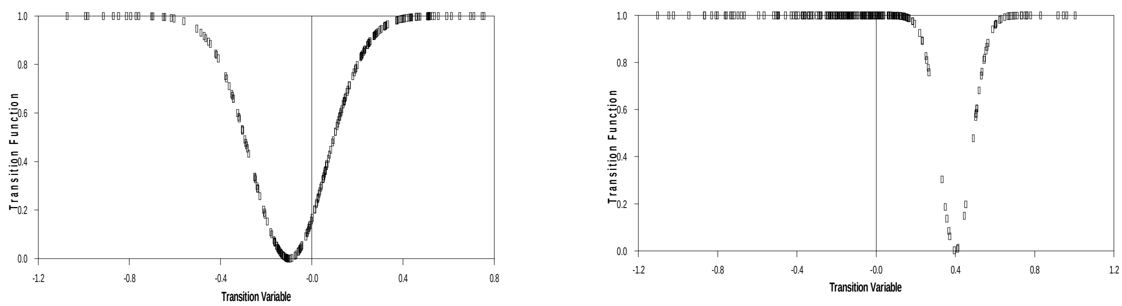

Figure 1 shows that an exponential function seems to be more appropriate for explaining the oil-equity relationship in the USA and France. For the latter, we clearly identify a central regime and two upper regimes. In the central regime, the oil price deviations are lower, the adjustment is absent and the price can deviate from the equilibrium. Oil price deviations are close to the unit root in this zone. However, in the upper regimes, when deviations become more important, the adjustment is activated and its convergence speed increases according to the size of oil price deviations. This also confirms that the oil price reacts asymmetrically to any stock market correction or shock.

The fact that transition function approaches unity and remains in the upper regime further indicates that the oil price adjustment for France and the USA is activated for a long period and that it is nonlinearly mean-reverting with an adjustment speed that increases with the size of the deviation from equilibrium. Indeed, the oil price may undergo some short-term disruptions, but it shares some similarities with the stock market's properties in the long term. The oil price and stock market may thus tie steady relations which converge toward an equilibrium for which the adjustment dynamic is nonlinear.

4. Conclusion

In this paper, we check the oil-stock market relationships in a linear and nonlinear framework. Our findings show strong evidence of a significant nonlinear cointegration relationship between the oil and stock markets for France and the USA. The ESTECM modeling is appropriate to the reproduction of the oil and stock price adjustment dynamics. Another important empirical finding concerns the specification of two distinct oil price regimes: a "pure chartist regime" for which the oil price adjustment is determined by its previous tendencies and a "stock market follower regime" for which the adjustment is more activated.

More interestingly, the oil price is nonlinearly mean-reverting toward the stock market equilibrium with an adjustment speed that increases according to the size of the disequilibrium. These results may also explain the alternation of stock and oil crises and the "co-movements" between oil and of stock prices. To conduct further research on this issue, it would be interesting to extend this study to another important group of developed and emerging countries and to generalize these nonlinear modeling techniques to a multivariate framework.

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