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Nonlinearities and the order of integration of oil prices

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Abstract

Unit root tests are the starting point of most empirical time series research. This paper analyses the order of integration of oil prices taking into account the possibilities of nonlinearities in the deterministic components. Using an aggregate index for the price of oil, and applying Bierens (1997) unit root tests, we find that the hypothesis of a unit root process is rejected in favour of nonlinear trend stationarity of the price of crude oil. On the contrary, preliminary analysis using Ng and Perron (2001) and Kapetanios, Shin and Snell's (2003) tests, fail to reject the hypothesis of a unit root.

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1 Introduction

Oil prices have acquired increasing relevance in modern economics. This is not only because oil is the base chemical product for producing fuels, plastics, etc., but also because in many countries, national income is heavily dependent on crude oil exports. Likewise, the relationship between oil prices and many macroeconomic variables have promoted many lines of research. Following the influential work of Hamilton (1983), the most fruitful area of this research focuses on the connection between GDP and oil prices. Although the initial steps of this literature found that a linear negative relationship between oil prices and economic activity fit the data relatively well, empirical work soon moved attention to asymmetric adjustment of GDP to oil price shocks. The estimated linear model began to lose significance around the mid-1980s when the declines in oil prices had little effect in GDP, with a smaller impact than predicted by linear regressions. Based on the (simple) observation that oil prices have a larger impact on GDP in positive than negative fluctuations, nonlinear models were proposed such as Mork (1989) , Lee, Ni and Ratti (1995), and Hamilton (1996), to capture the complexity of this relationship. More recently, Jimenez-Rodriguez and Sanchez (2005) present evidence using the aforementioned three nonlinear transformations, while Hamilton (2002 and 2003) proposes a more flexible approach to nonlinear modeling. Complementary research has explored association of oil prices with other variables. Several papers have studied the long-run co-movement of oil prices and inflation (such as Cuñado and Perez de Gracia, 2005), among which, more interestingly, some few have estimated the Phillips curve augmented with the price of oil (Hooker, 2002, and LeBlanc and Chinn, 2004). A number of authors have acknowledged the effects of oil prices on the dynamics of unemployment (see Gil-Alana, 2003, among others) international terms of trade (Backus and Crusini, 2000). Finally, in addition to the influence of oil prices in modern macroeconomic dynamics, the increasing of crude oil prices has induced much attention in the forecasting of oil prices (see Lanza, Manera and Giovannini, 2005, and Abosedra, 2005).

This vast bibliography indicates the importance of the study of the dynamic behavior of oil prices. The analysis of the long run properties of macro time series has captured the attention of many authors during the last two decades. This interest was (probably) boosted by Nelson and Plosser's (1982) seminar paper in which the authors argue that many economic series are better characterized by unit roots. Since then, the analysis of the order of integration of macroeconomic variables has become an increasingly popular topic amongst applied time series econometricians.

Over the last two decades, many authors have contributed to the literature on unit root testing. This line of research has provided alternative approaches to the traditional Augmented Dickey-Fuller (ADF) unit root test, given the poor performance of this test in terms of power in short samples (see Phillips, 1987; Phillips and Perron, 1988; and Kwiatkowski et al., 1992), fractional integration (Geweke and Poter-Hudak, 1983; and Robinson, 1994), structural changes (Zivot and Andrews, 1992; Perron, 1989, 1990, 1997; Perron and Vogelsang, 1992a, 1992b; Lumsdaine and Papell, 1997; and Perron and Rodríguez, 2003) and nonlinearities (Bierens, 1997; Leybourne et al., 1998; and Kapetanios, et al., 2003) in the data generating process.

Regarding the previous literature about the long run behaviour of the oil prices, there is no consensus whatsoever about the order of integration of this variable. For instance, Bentzen (2007), Cuñado and Pérez de Gracia (2005), and Jalali-Naini and Asali, (2004), find that the crude oil price contains a unit root, whereas Postali and Picchetti (2006) find that this variable is stationary with structural changes. In addition, Gil-Alana (2001, 2003) finds that the real price of oil is a fractional integrated process.

Previous research has mainly focused on the application of standard unit root tests with almost no consideration of any nonlinearity in the deterministic components, under the alternative hypothesis. The consequences for the results are important since an incorrect specification of the deterministic component might affect the power of the test, i.e. over non-rejection of the null hypothesis of unit root (see Perron and Phillips, 1987; and West, 1988, among others). If one generalizes the case of structural changes in the drift and time trend, the result is a nonlinear deterministic trend (Bierens, 1997).

We contribute to this literature by examining the order of integration of the crude price oil by applying the Bierens' (1997) and Kapetanios, Shin and Snell (2003) unit root tests. Both depart from the null of a unit root. Under the alternative hypothesis, Bierens (1997) takes into account the possibility of nonlinear trend stationarity while Kapetanios, Shin and Snell (2003) introduce a globally stationary exponential smooth transition autoregressive (ESTAR) process. Although both tests take into account the existence of nonlinearities, the former can be adapted to a broad range of alternative nonlinear models while the latter considers the implications of a particular kind of nonlinear dynamics. In particular, the ESTAR model is flexible in dealing with potential asymmetric behavior or multiple regimes. Based on a Kapetanios, Shin and Snell (2003) unit root test, we do not find evidence of stationarity. Instead, the existence of a unit root is rejected when the polynomial approximation of Bierens (1997) is proposed.

The implications of the results are important not only from a theoretical point of view, but also for policy making decisions. Should the price of oil be an integrated process, any shock over the variable has permanent effects and will never return to its fundamental equilibrium. In this case, any policy decision to affect the path of oil prices will not have any effects, since new shocks will cancel out the former. On the other hand, if the price of oil is a stationary process, shocks only have transitory effects, and the variable will tend to revert to its fundamental equilibrium in the long run. Therefore, policymakers may have some discretionary power over oil prices only in this second case.

The remainder of the paper is organized as follows. The next section summarizes the econometric methodology and the empirical results, whereas the last section concludes.

2 Empirical analysis

The data were collected from the *Datastream* database and consists of daily observations of the S & P crude oil spot price index from January, 1st, 1987 until June, 10th, 2008, (5,594 observations). The time series is plotted in figure 1. The preliminary analysis of linear unit root tests follows Ng and Perron (2001). These authors propose several modifications of existing unit root tests in order to improve their finite sample performance. The tests replace the AIC and BIC criteria, which tend to select a too small truncation lag for the augmented autoregression, for a new Modified Information Criterion (MIC), leading to important size improvements in Monte Carlo simulations. Prior to this, the time series is de-meaned or detrended by applying a GLS estimator. In table 2 we report the results of these tests for a model with linear trend and drift. From this table we can summarize that the unit root hypothesis cannot be rejected at the usual critical levels.

It is common to model macroeconomic variables as I(1) processes instead of trend stationary variables. However, traditional unit root tests, even with structural changes, might incorrectly conclude that the series are I(1) when in fact they are stationary around a nonlinear deterministic trend. Some motivation for the potential importance of nonlinearities in oil prices can be found in the literature of oil prices and GDP. From the second half of 1980s, there is little evidence of a linear relationship between the two variables. Instead, several models with multiple regimes have been proposed. Mork (1989) is the first to consider asymmetric responses of economic activity to oil price increases and decreases. Raymond and Rich (1997) make use of the two-regimen Markov-Switching Model of Hamilton (1989) to explain USA output growth using oil price increases. Clements and Krolzig (2002) use a Markov Switching Model for changes in output and employment. Three State Markov Switching model is their preferred model to use oil prices to explain the business cycle.

The loosening of this bivariate linear relationship between oil prices and GDP may also suggest any ADF or similar specification is a simplistic approach to the univariate case. Oil prices dynamics may be too complex to be modeled by a linear autoregressive function. If so, the linear model may be misleading, biasing the results in favor of the unit root hypothesis. In order to take into account nonlinearities due to multiple regimes, we perform Kapetanios, Shin and Snell's (2003) (KSS) unit root test to the detrended and demeaned data[1]. The alternative hypothesis of the KSS test is a globally stationary smooth transition autoregression, where the inner regime is allowed to have a unit root. Thus, KSS's approach is based on the following modified ADF equation,

$$\Delta y_t = \alpha y_{t-1} + \gamma y_{t-1}(1 - exp\{-\theta y_{t-1}^2\}) + \epsilon_t. \tag{1}$$

Note that this regression implies that the autoregressive parameter changes smoothly depending on the values of the variable y_t. Since KSS impose $\alpha = 0$, the variable is assumed to be a unit root in the inner regime. In order to test the null hypothesis of a

[1] In particular, KSS assumes a three-regime model.

unit root, $H_0 : \theta = 0$, against the alternative of a globally ESTAR process, $H_1 : \theta > 0$, KSS propose the following Taylor approximation of model (1), given that the coefficient γ cannot be identified under H_0,

$$\Delta y_t = \delta y_{t-1}^3 + error \tag{2}$$

It is now possible to apply a t-statistic to test whether y_t is a unit root process, $H_0 : \delta = 0$, or is a stationary process, $H_1 : \delta < 0$. The results of the KSS test, reported in the last column of table 2, point to the non-rejection of the unit root hypothesis.

Alternatively, structural breaks may be another type of nonlinearity to deal with. From figure 1, it is clear that the price of oil has suffered from important increases during the last seven years. These increases are shown in a convex upward sloping trend (dotted line in figure 1). Also, the same graph shows an additional cyclical component affecting the short run dynamics during the whole sample. These two sources of nonlinearities in the deterministic component might affect the results of the unit root testing if they are not accounted for. The traditional approach would be to introduce at least a structural break in the (linear) deterministic trend[2], most likely between 1999 and 2001, introducing the nonlinearity in the long run. However, structural breaks assume the transition to the post break dynamics is immediately. In addition, they do not deal the existence of any cyclical component.

[2]Which may include a drift, or a drift and a trend.

An alternative approach is to use a more general nonlinear trend stationary process motivated by smooth rather than sudden breaks. In the case of a structural break, a functional approximation proposes a smooth transition to the new long run which may be more realistic than a sudden change. In addition to structural breaks, the functional approximation may deal with other nonlinearities such as the existence of a deterministic cyclical component. Park and Choi (1988) and Ouliaris, Park and Phillips (1989) first suggested the use of ordinary time polynomials in various standard unit root tests to capture the presence of structural changes in the deterministic components. Bierens (1997) explores this idea by introducing Chebishev polynomials in the auxiliary ADF regression as a functional approximation of the nonlinear deterministic trend. As the author points out the use of Chebishev polynomials has several advantages over ordinary time polynomials, i.e. it is possible to distinguish between linear trend stationarity and nonlinear trend stationarity under the alternative hypothesis. Hence, Bierens (1997) proposes a unit root test based upon the following auxiliary ADF regression:

$$\Delta x_t = \alpha x_{t-1} + \sum_{j=1}^{p} \phi_j \Delta x_{t-j} + \theta^T P_{t,n}^{(m)} + \varepsilon_t \tag{3}$$

where $P_{t,n}^{(m)}$ are the Chebishev polynomials of order m. The null hypothesis is formulated such that α and the last m components of θ are not significant. In this paper we apply the $\hat{t}(m)$ test, which is a t-test on the significance of the coefficient α. In addition, and in order to check the robustness of the previous results, we also apply the $\hat{A}(m) = \frac{n\hat{\alpha}}{|1-\sum_{i=1}^{p}\hat{\phi}_i|}$ test, an alternative test for the same hypothesis. The distinction between linear or nonlinear trend stationarity depends upon the side of the rejection. Whereas right side rejection implies stationarity around a nonlinear deterministic trend, left side rejection does not allow us to distinguish between mean stationarity or stationarity around a deterministic trend (see Table 1).

In table 3 we display the results for the Bierens' (1997) unit root test. The lag length for the auxiliary ADF regression has been selected by the Akaike Information Criterion (AIC). Following Bierens (1997) there is not a unique criterion to choose the order of m. A too low order of m might not be enough to capture any nonlinearity, which may affect the power of the test, whereas a too high order of m might imply the estimation of redundant parameters[3]. In the table we present the results of these tests for different orders of m. Both tests reject the null hypothesis of unit root test in favor of the alternative of stationarity. Since in both cases and for any order of m we obtain right side rejection, table 3 suggests the series of crude oil price is stationary around a nonlinear deterministic trend, implying there is a time varying equilibrium.

Our results pin point the importance of taking into account a proper specification of the deterministic components when analyzing the order of integration of crude oil prices.

[3]The less linear the deterministic trend is, the higher the order of m is. Likewise, a high order of m would reproduce oscillatory behavior if there is a cyclical deterministic component.

3 Conclusions

Aimed at contributing to the literature on the long run behavior of the crude oil prices, we have applied Bierens (1997) unit root test which takes into account the existence of nonlinear trend stationarity under the alternative hypothesis. Our results indicate that this variable is a stationary process around a nonlinear deterministic time trend, and the results do not depend on the order of the Chebishev polynomial. In addition, these results give us some insights about the effects of policy decisions on the long run behavior of oil prices.

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Figure 1: S & P Oil price index

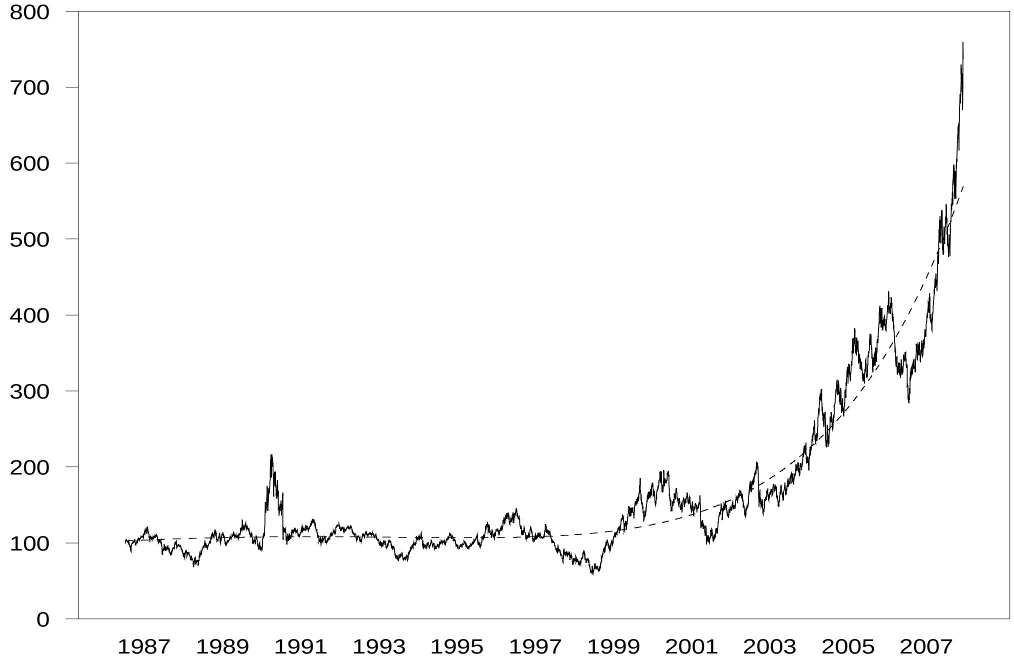

Table 1: Alternative hypotheses

Test	**Left-side rejection**	**Right-side rejection**
$\hat{t}(m)$	MS, LTS or NLTS	NLTS
$\hat{A}(m)$	MS, LTS or NLTS	NLTS

Note: MS= mean stationarity, LTS= linear trend stationarity, NLTS= nonlinear trend stationarity.

Table 2: Ng and Perron (2001) and Kapetanios (2003) unit root tests results

MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}	**KSS**
3.39078	1.21304	0.35775	50.4050	3.01569

Note: The order of lag to compute the test has been chosen using the AIC. The critical values for the above tests have been taken from Ng and Perron (2001) and Kapetanios (2003), respectively:

Model with constant and linear trend

	MZ_{α}^{GLS}	MZ_{t}^{GLS}	MSB^{GLS}	MP_{T}^{GLS}	**KSS**
1%	- 23.80	-3.42	0.14	4.03	-3.93
5%	-17.30	-2.91	0.16	5.48	-3.40
10%	-14.20	-2.62	0.18	6.67	-3.13

Table 3: Bierens (1997) unit root test results

m	$\hat{t}(m)$	CV (5%)	CV (10%)	CV (95%)	CV (90%)	$\hat{A}(m)$	CV (5%)	CV (10%)	CV (95%)	CV (90%)
3	-0.631	-4.68	-4.43	-1.72	-1.94	-4.741	-40.40	-35.60	-7.30	-8.50
4	-0.912	-5.08	-4.80	-1.59	-1.91	-6.928	-46.50	-41.40	-7.40	-9.30
5	-1.880	-5.43	-5.16	-2.43	-2.63	-16.582	-53.80	-48.70	-13.50	-15.10
6	-1.817	-5.80	-5.49	-2.42	-2.69	-16.027	-60.10	-54.70	-14.40	-16.80
7	-2.097	-6.09	-5.78	-3.00	-3.21	-19.081	-67.50	-61.80	-20.00	-22.30
8	-2.163	-6.41	-6.08	-3.05	-3.33	-19.678	-73.50	-67.90	-21.90	-24.50
9	-2.166	-6.68	-6.35	-3.54	-3.76	-19.711	-80.20	-74.40	-27.00	-29.80
10	-2.755	-6.98	-6.67	-3.58	-3.86	-28.908	-87.00	-80.30	-29.60	-32.60

Note: Results obtained with the software Easyreg International by Bierens. The order of lag has been chosen by the AIC. CV stands for critical value.

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