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Are electricity prices affected by the US dollar to Euro exchange rate? The Spanish case

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ABSTRACT

The objective of this paper is to investigate the relationships between Spanish electricity spot prices and the US dollar/Euro (USD/Euro) exchange rate during the period 2005–2007, taking into account the study of the association between dollar and oil prices, in order to better understand the evolution of the former over time. The first finding in this study is that Spanish electricity spots prices, the USD/Euro exchange rate and oil prices are cointegrated; therefore there is a long-run equilibrium relationship between the three variables. Short-run relationships have been detected between oil prices and Spanish electricity prices and USD/Euro exchange rate in the sense that Spanish electricity prices and USD/Euro exchange rate are affected by oil prices in the short run. There is a transmission of volatility between USD/Euro exchange rate and oil prices to Spanish electricity prices; so although Spanish electricity prices are not affected in level by the movements of USD/Euro exchange rate, they are in volatility. In this kind of scenario the conclusions confirm that for countries so dependent on external causes as Spain, one possible solution for guarantying the energy security would be the promotion of the renewable energies. Therefore we cannot ignore the impact in the internal expenses of the cost of installation and generation of green energies so there must be a balance between the increase in renewables and the reasonable market price of the electricity.

1. Introduction

The liberalization and deregulation of the electricity markets in developed countries during the last 15 years has triggered important changes in the management of electric companies as well as for their largest customers due to price volatility and changing market conditions. Electricity can be considered a commodity and has characteristics that make its prices especially volatile. The demand has to be satisfied in real time; in technical terms it is almost impossible to store it; and many of its inputs — like gas, coal and petroleum-derived products — also have very volatile prices.

The current volatile financial market makes it very difficult to predict the price behavior even more in the case of the power market. That makes it crucial to know what the possible external causes are. This fact is emphasized on the Spanish market due to the fact that Spain has to import most of her commodities. A detailed description of the current Iberian electricity market can be found in Fernández-Domínguez and Xiberta-Bernat (2007). Bunn and Fezzi (2007) show that for the British market, the price of electricity is related to the prices of gas and coal.

The objective of this paper is to investigate the relationships between Spanish electricity spot prices and the US dollar/Euro (USD/Euro) exchange rate, taking into account the study of the association between dollar and oil prices, in order to better understand the evolution of the former over time. In this kind of scenario the conclusions confirm that for countries so dependent on external causes as Spain, one possible solution for guarantying the energy security would be the promotion of the renewable energies. The Spanish government, signee of the Kyoto protocol, has a special sensibility towards the promotion of the renewable energy with the goal of reducing the greenhouse gases. Therefore we cannot ignore the impact in the internal expenses of the cost of installation and generation of green energies so there must be a balance between the increase in renewables and the reasonable market price of the electricity.

Nowadays the USD is the most important reserve currency in the world and most of the international commercial transactions are made in dollars. It is very well known that commodity prices, for example oil, gas, and coal, are affected by the USD movements, given that those prices are generally quoted in USD. Gas, coal and oil, in this order, are the main components of Spanish electricity generation, and of electricity prices as well. In addition, Spain has to import most of the resources needed for generating electricity. Knowledge of the relationship between the exchange rate of USD/Euro and electricity prices can be a big help for

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the Spanish electricity market in order to control and avoid, as far as possible, future risks.

One of the first studies on the relationships between future energy prices and exchange rates was done by Sadorsky (2000) who investigated the long-run relationships between them. Lemming (2003) highlights in his Ph. D. thesis that exchange rate fluctuations in the Nordic power market, Nord Pool, are possible causes of an additional cost risk. In a similar way, the Ontario Energy Board in its report of May 2008 emphasizes that exchange rate is one of the factors that affects electricity prices because generators purchase fuels in U.S. dollars. Recently Veith et al. (2009) proposed a multifactor model for the European power sector with the aim of estimating the relationship between the stock prices and the prices of emission rights. In this model they introduce the local exchange rate between the local currency and the USD as an input variable because of the importance that the exchange rate has in the evolution of electricity prices.

Blomberg and Harris (1995) already point out that *"commodity movements are a reaction to swings in dollar exchange rates rather than a signal of generalized inflation pressures"*. There is a lot of literature analyzing the relationships between oil prices and exchange rates. Among others, Camero and Tamarit (2002) analyze the factors that affected the real exchange rate of the Spanish peseta and conclude that increases in real oil prices tended to cause depreciation in the peseta while Narayan et al. (2008) conclude that a rise in the oil price tends to produce an appreciation of the Fiji/USD exchange rate. Chen and Chen (2007) investigate the long-run relationship between oil prices and real exchanges rates for the G7 countries, suggesting that real oil prices could be a good predictor of the real exchange rates. Indjehagopian et al. (2000) who study the German and French heating oil market conclude that weekly variations of the DM/USD and FF/USD exchange rates instantaneously affect heating oil prices in these countries. Yousefi and Wirjanto (2004) comment that, for OPEC member countries, there is a link between oil prices and the USD exchange rate which allows these countries to benefit when the dollar is strong. Simpson (2007) uses a global stock price index, built from Datastream, to show that changes in daily oil prices are produced by changes in the global stock index and coal price; also he concludes that movements in gas prices are associated with changes in oil prices. Amano and van Nordem (1998) state that *"the macroeconomic importance of oil prices may also be increased because of the fact that other forms of energy (coal, gas, and to a lesser extent electricity) are sometimes priced in order to compete with oil, so that oil price fluctuations become reflected in broader energy price fluctuations"*.

In relation with the stock market effects of energy prices, Sadorsky (1999) affirms that oil prices and their volatility can affect the economy in an asymmetric way, in the sense that variations in oil prices affect the economy but changes in the economy have a low effect on oil prices. Boyer and Filion (2007) explain the stock returns of oil and gas firms by means of including in a statistical model natural gas and other factors associated to the applicable industry. Recently, a first analysis on the determinants of returns and volatility of Eurozone energy stocks has been done by Oberndorfer (2008a), in which the author points out that *"at least European oil and gas stocks may offer a relatively weak performance in times of high oil price volatility"*.

Concerning the European Community there has been a recent analysis of the impact of exchange rate shocks on sectorial activity and prices in the Euro area (Hahn, 2007). In this study the conclusion in relation to the price is that the impact of the exchange rate shocks is not homogeneous within the different industrial sectors from the Euro zone. In addition, the impact is greater in the industrial sectors related to electricity generation, gas and water distribution, being that the prices related to energy production are those that are more affected by an abrupt variation in the exchange rate.

The previous references point out that the movements of oil, gas and coal prices are related to the exchange rates, as are the electricity prices. This evidence reinforces the importance of analyzing jointly the effect of the USD/Euro exchange rate and oil prices on the Spanish electricity spot price.

This paper is structured as follows: Section 2 shows the data description and the main features; unit roots, cointegration and causality tests are in Section 3; estimated volatilities are in Section 4; and finally Section 5 presents the conclusions of the study.

2. Data

This section carries out a descriptive analysis of the Spanish electricity spot prices (SEP), the exchange rate of USD/Euro (EDER) and the daily Europe Brent Spot Price in dollars per barrel (OIL_DOL). The study covers the period starting on January 3, 2005 and ending on December 31, 2007. Our choice for this sample period is because in Spain in particular as in other European countries the electricity prices increased a lot in 2005. In addition, on January 2005 the EU-wide CO_2 greenhouse gas emission trading system (EU TS) has formally entered into operation. For these reasons we avoid using data from periods before 2005. OIL_DOL data are downloaded from the US Energy Information Administration.[1] This series is denominated in dollars and not in Euros to avoid using the exchange rate two times: as independent variable and also in the conversion of oil prices to Euros. Working days are used because, although SEP is available for all calendar days (www.omel.es), EDER (www.statistics.dnb.nl) and OIL_DOL are only available for working days. In the case of holidays, the missing value in USD/Euro and/or OIL_DOL is replaced by the last trading value. The number of observations used in each series is 775. Fig. 1 confirms the feeling that the evolution of electricity prices, SEP, and USD/Euro exchange rate, EDER, are very similar. The data are analyzed using the R: a language and environment for statistical computing (R Development Core Team, 2006) and the SAS System for Windows V9.2 (2008).

Preliminary analysis showed that a log transformation is neither necessary for electricity prices nor for USD/Euro exchange rate and oil prices. Furthermore log transformation of these series would reduce their volatility magnitude, masking perhaps the statistical relationships that we want to analyze (Karakatsani and Bunn, 2008; Zhang et al., 2008). Summary statistics of these series are in Table 1.

From the summary statistics we can conclude that the three time series exhibit asymmetry (significant skewness) but only the SEP does not have significant kurtosis, showing that in this case, because the kurtosis value is negative, the SEP data are lighter tailed than the Gaussian data; so neither the electricity price series nor the exchange rate series and oil prices follow a Gaussian distribution. This result is also confirmed by the Jarque-Bera test. Furthermore, autocorrelation and autocorrelation of squared values are significant for the three time series; this latter result is related to the existence of volatility clusters.

The study period is characterized by a rough USD appreciation of about 4.5% against the Euro during the first and second quarters of 2005; the appreciation against the Euro decreases in the third quarter of 2005 being only 0.7%, this quarter coinciding with the event of Hurricane Katrina (August 2005) and with the appreciation of the Canadian dollar, *"which was perceived to benefit from rising commodity prices"* (the Federal Reserve Bank of New York), ending this year with the depreciation against the Euro in November of this year. This depreciation continues with a rapid rate, more or less, throughout the years 2006 and 2007.

Some justifications of these depreciations can be found in the economics literature. Among others, the Federal Reserve Bank of New York (2005), in its Treasury and Federal Reserve Foreign Exchange Operations: Quarterly Reports, notes that *"between mid-October and early December, 2006, the dollar depreciated 6.6% against the Euro, reaching its lowest level against the Euro since March 2005; disappointing U.S. manufacturing and housing data led market participants to lower their expectations for the U.S. economic growth outlook during this period"*.

[1] EIA: http://tonto.eia.doe.gov/dnav/pet/hist/rbrteD.htm.

Concerning the third quarter of 2007, this period also saw a large depreciation against the Euro (5.4%) and against the yen (6.8%). The explanation now of those depreciations is that they were *"driven mainly by changes in relative growth expectations and interest rate differentials"*. Finally in the last quarter of 2007, the dollar's depreciation, the macroeconomic outlook and bank balance sheets were affected, respectively, over this period by negative government outlook data, weak financial performance in the housing sector, and write-downs on leveraged loans and mortgage positions as well as loan loss provisions. All of these factors led to general pessimism regarding U.S. economic growth and a subsequent decline in consumer confidence, despite robust employment data. This strongly negative performance contrasts with the Japanese and European data over the same period.

Table 1
Summary statistics.

Statistics[1]	SEP	EDER	OIL_DOL
N	775	775	775
Mean	5.099	0.778	64.039
St. Dev	1.403	0.044	11.230
Skewness	0.646 (2.147e-13)	−0.307 (0.0005)	0.646 (2.105e−13)
Kurtosis	−0.151 (0.390)	−0.540 (0.002)	0.336 (] 0.057)
JB statistic	54.741 (1.298e−12)	21.444 (2.205e-05)	57.940 (2.622e-13)
Q(20)	7270.961 (<2.2e-16)	13798.9 (<2.2e-16)	12062.80 (<2.2e-16)
$Q^2(20)$	781.327 (<2.2e-16)	13814.7 ((<2.2e-16)	12028.71 ((<2.2e-16)

Notes:
p values are displayed as (.) JB statistic is the Jarque Bera statistic to test normal distribution. Q(20) and $Q^2(20)$ are Ljung-Box statistics lagged until 20 periods to test the autocorrelation of the original and squared series respectively.
Working days data (2005–2007).

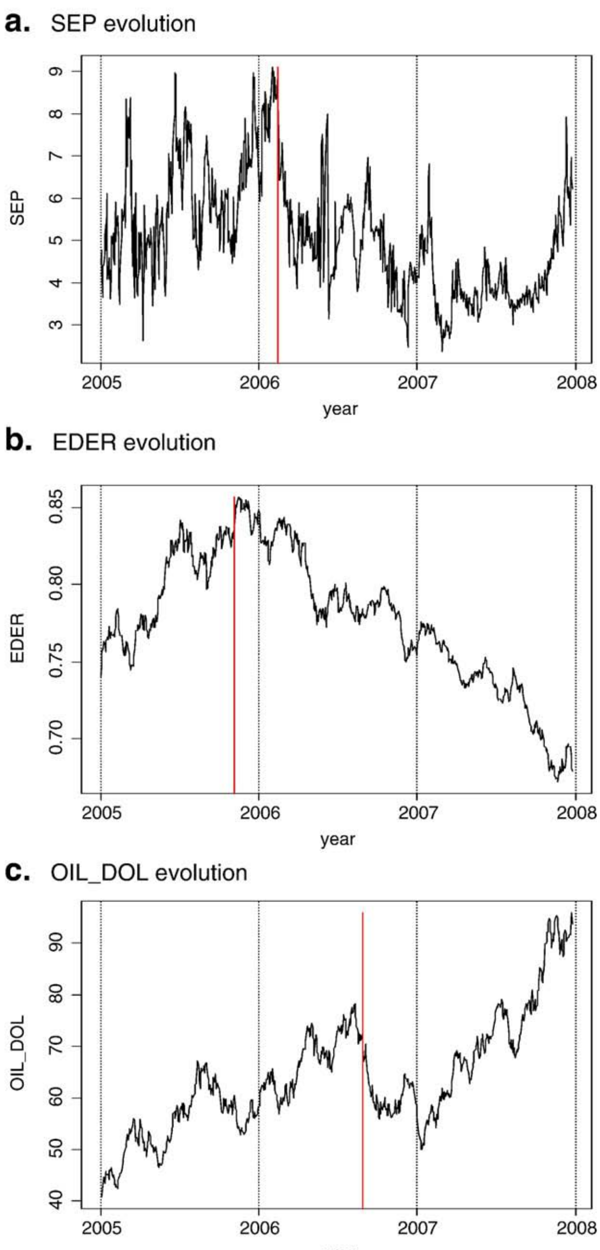

Fig. 1. Evolution of the SEP, EDER and OIL_DOL variables. *Notes*: SEP is the Spanish electricity spot price, EDER is the USD/Euro exchange rate and OIL_DOL is the Europe Brent spot price in dollars. In red: the breakpoint detected by Zivot and Andrews test. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Another characteristic of this period is the strong increase of the petroleum price in 2005, that closed the year at around 60 dollars per barrel, nearly double the levels reached at the beginning of 2004. The Bank of Spain affirms that: *"The escalation in crude prices in biennium 2004–2005 has been, mainly, a consequence of the strong growth of its demand on the part of the most dynamic economies, in particular China and the United States, as well as of the low capacity of production and refining"*. Fig. 1 shows that the price of petroleum continues to increase.

Particular attention has to be paid to the evolution of Spanish electricity prices at the beginning of 2007. Although the demand for electricity in Spain keeps growing (see Fig. 2), the decrease in prices at the beginning of 2007 could be caused by the change in the Electricity Market law, approved by the Spanish government at the end of 2006. This law allows moving this market from defended to more competitive; the application of this law includes among others, the development of a unique market for Spain and Portugal and the starting of the electricity future market.

To better understand the increase in the electricity prices from the halves of 2007 it's necessary to take into account the information about the consumption of primary energy in Spain (Fig. 3); 51% of this energy is generated by fossil fuels (coal 25.7%, fuel–gas 7% and combined cycle[2] 24.4%). The constant rise in fuel prices in 2007 could have influenced the increase of electricity prices because of the increase in production costs. Regarding the cost of CO_2 emissions it is not clear that they are the possible causes of increasing prices because the Spanish electricity market has played a different role, as Oberndorfer (2008b) pointed out that the inverse effect of the EUA on Spanish corporations may arise from stringent price regulations on the Spanish market, where — in contrast to other EU countries — cost pass-through is not possible. In this case it is possible that generators pass on CO_2 emission costs to the consumers.

3. Unit roots, cointegration and causality

Through the inspection of Fig. 1, with exception of the last period of 2007, it seems intuitively clear that the time series built from the Spanish electricity spot prices and the USD/Euro exchange are two parallel non-stationary time series in the sense that they move together, which means that the difference between observations at any certain time remains approximately constant throughout the whole time period. This is the intuitive idea of cointegration, introduced by Granger (1981) and later published by Engle and Granger (1987) in their seminal paper.

As has been previously mentioned, the concept of cointegration is applied to non-stationary time series; so before testing cointegration,

[2] Combined cycle: gas turbine plants driven by both steam and gas.

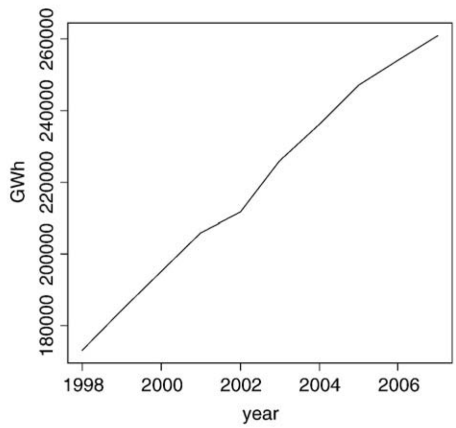

Fig. 2. Spanish Peninsular Demand (Source: Red Electrica Española, REE).

it will be necessary to check if these time series are integrated of order one (I(1) in abbreviated form). In this paper time series non-stationarity will be verified by testing the existence of a unit root by means of the augmented test of Dickey and Fuller, ADF (Said and Dickey, 1984) and in order to test the stationarity in the presence of structural breaks, the Zivot and Andrews test (1992) will be applied.

In order to detect the existence of cointegration relationships, we conduct the two-variable cointegration tests here for illustration only, improving on them later by adding a third variable and switching to a test that is justified for more than two variables. The following tests will be applied for the two-variable model: the Engle and Granger test and Gregory and Hansen test (1996) that use an approach similar to the Zivot and Andrews test with the idea of modifying the Engle and Granger test, including structural breaks and the variation of the Johansen test introduced by Lütkepohl et al. (2004) for detecting level shifts in VAR models. VECM and VECM with level shift will be used in the three-variable models. Finally causality relationships will also be studied.

3.1. Unit root tests

3.1.1. Augmented Dickey and Fuller test (ADF)

The results of applying the ADF test to the EDER, SEP and OIL_DOL are reported in Table 2. From the previous results in Table 2 it is clear that EDER and OIL_DOL are not stationary and first differencing is needed but it is not clear that SEP is integrated of order 1, I(1). The mean of electricity prices cannot be assumed to be zero and the tests that allow a mean or trend reject I(1), however this is contingent upon the model assumptions being valid. This includes the assumption of no structural breaks.

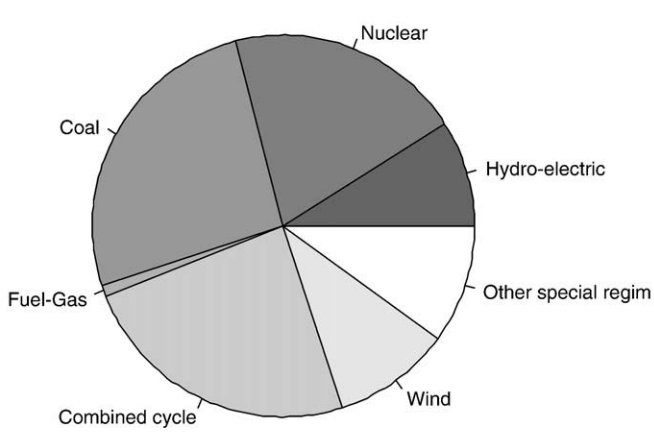

Fig. 3. Consumption of primary energies in the power generation, 2007 (Source: Red Electrica Española, REE).

Table 2
Unit root tests: augmented Dickey and Fuller (ADF).

Variables	ADF tests in level data			ADF tests in first differences data		
	Zero mean	Single mean	Trend	Zero mean	Single mean	Trend
SEP	−0.62	−3.30	−3.84	−25.19	−25.18	−25.16
	(0.45)	(0.02)	(0.02)	(<.0001)	(<.0001)	(<.0001)
EDER	−0.83	0.02	−2.07	−27.68	−27.68	−20.34
	(0.36)	(0.96)	(0.56)	(<.0001)	(<.0001)	(<.0001)
OIL_DOL	1.37	0.85	−1.87	−19.51	−19.59	−19.58
	(0.96)	(0.80)	(0.67)	(<.0001)	(<.0001)	(<.0001)

Note:
$\nabla Y_t = Y_t - Y_{t-1}$. The null hypothesis is that there is a unit root ($\rho = 0$). Under the null hypothesis, $\tau = \hat{\rho}/SE(\hat{\rho})$ follows a specific distribution which is not a Student t-distribution. The value of the τ-statistic has to be compared with the critical values tabulated in Dickey and Fuller (1979). Failure to reject the null hypothesis means that there is no strong evidence against the hypothesis that the time series is not stationary. The p values are displayed as (.). The number of lags k is set at 6 in level data and at 1 in first differences data.
The ADF test is an extension of the Dickey and Fuller (1979) applied to the following models:
Zero mean: $\nabla Y_t = \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$
Single mean: $\nabla Y_t = \alpha + \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$
Trend: $\nabla Y_t = \alpha + \beta t + \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$
where e_t is random noise.

3.1.2. Zivot and Andrews test for unit root with structural breaks

Structural breaks in a time series, caused for example by a shock, can change the properties of traditional unit root tests, affecting the conclusions of these tests. Zivot and Andrews (1992) proposed to introduce a dummy variable in the regression models formulated by Dickey and Fuller in their seminal paper. This dummy variable will detect the structural break that in general is unknown. The estimation of the position of the structural break is done sequentially. The results of applying the Zivot and Andrews test to the time series of this study together with the statistical values and critical values are in Table 3.

For the EDER the conclusion is that the null hypothesis of a unit root with breakpoint cannot be rejected at a significance level of 5%. The three breakpoints detected are different but all of them are detected in 2005. The most realistic one assumes that there is a breakpoint that produces a change in the trend (model B). This breakpoint is located on November 4th 2005, the month which saw the start of the depreciation of the USD against the Euro, as pointed out by the Federal Reserve Bank of New York (2005).

For the SEP, the most appropriate model is the one that takes into account a breakpoint at the beginning of 2006 in the intercept and slope (model, C); and the null hypothesis cannot be rejected for this model at a 1% significance level. This model has also been selected for the OIL_DOL variable, with a breakpoint located on August 25th 2006. The explanation of these breakpoints for both series is that since February–March of 2006, electricity prices in Europe showed a tendency to drop following the energy commodities. *"This convergence of Spanish electricity prices with European prices is due to two facts: first of all, the incidence of the commodities prices has a similar effect in the majority of European markets, and also for the fact that the Spanish Electricity Market is open to trading for agents from other countries who have participated with normality since 1999"* (OMEL, Annual report 2006). Additionally, one of the strongest increases of the petroleum prices started during the last quarter of 2006.

Fig. 1 shows the estimated timing of the level shift. This time coincides with the continuous depreciation of the USD/Euro exchange rate and with the beginning of the increase of electricity prices in Spain caused by increases in the prices of fossil fuels.

Table 3
Zivot and Andrews test for unit root with structural breaks.

Variables	Model selected	ZA statistics	Critical values			Breakpoint
			1%	5%	10%	(mm/dd/year)
SEP	C	−5.29	−5.57	−5.08	−4.82	02/13/2006
EDER	B	−4.27	−4.93	−4.42	−4.11	11/04/2005
OIL_DOL	C	−4.79	−5.57	−5.08	−4.82	08/25/2006

Notes:
The null hypothesis is that there is a unit root with drift and/or break at an unknown point against the alternative, stationary trend with break in intercept or trend at an unknown point. Critical values reported are associated with the model selected.
Zivot and Andrews test applied to the following models:

- Model A, intercept: $\nabla Y_t = \alpha + \theta_1 U_t(\lambda) + \beta t + \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$;
- Model B, trend: $\nabla Y_t = \alpha + \beta t + \theta_2 T_t(\lambda) + \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$
- Model C, both: $\nabla Y_t = \alpha + \theta_1 U_t(\lambda) + \beta t + \theta_2 T_t(\lambda) + \rho Y_{t-1} + \sum_{j=1}^{k} \gamma_j \nabla Y_{t-j} + e_t$.

Where $U_t(\lambda)=1$ if $t>\lambda$ and 0 otherwise and $T_t(\lambda)=t-\lambda$ for $t>\lambda$ and 0 otherwise.

From the previous result, the non-stationarity of the three time series can be assumed because the null hypothesis of a unit root with drift at an unknown point cannot be rejected; it is appropriate to verify that both time series are cointegrated, starting with the simplest test proposed by Engel and Granger.

3.2. Cointegration test

3.2.1. Two-variable models

3.2.1.1. Engle and Granger cointegration test. The results of regressing SEP on EDER together with the critical values tabulated by Engle and Granger (1987) are in Table 4. In this case, the null hypothesis of no cointegration has to be rejected.

- *Cointegration tests with structural breaks*:

The period of this study includes the time in which oil prices increased and USD has had the biggest major depreciation against the Euro, therefore it is important to test if the cointegration relationships are affected by structural breaks given that failure to detect a break can affect the decision about the existence of cointegration relations. Two approaches are selected in this work, the Gregory and Hansen test that modifies the Granger and Engel test and the vector error correction model (VECM) with level shift proposed by Lütkepohl et al. (2004) that adopts the Johansen test to this case.

3.2.1.2. Gregory–Hansen cointegration test. Gregory and Hansen (1996) modified the Granger and Engel cointegration test by introducing in the regression equation the idea proposed by Zivot and Andrews (1992) of detecting an unknown breakpoint. In this case, as in the previous test, the null hypothesis is no cointegration. The results obtained together with the critical values are in Table 5, showing that the null hypothesis has to be rejected, in other words, both time series are cointegrated with a breakpoint affecting the intercept and slope on the estimated regression.

Table 4
Engle and Granger cointegration test.

Estimated equation			
$SEP_t = -8.51 + 17.49EDER_t + e_t$			
τ statistic	Critical values		
	1%	5%	10%
−7.22	−3.77	−3.17	−2.84

Notes:
The null hypothesis is no cointegration. Engle–Granger proposed two steps for testing the null hypothesis, regress y_t on x_t and keep the residuals e_t, apply ADF test to e_t, that is, regress ∇e_t on e_{t-1}: $\nabla e_t = a_0 + a_1 e_{t-1} + u_{t-1}$, calculate τ statistic as $\tau = \alpha_1 / s_{a1}$ and compare the value of the τ statistic with the critical values tabulated by the authors in Engle and Granger (1987).

3.2.1.3. VECM and structural shift. Johansen (1988, 1991) extended the error correction model proposed by Engle and Granger to the multivariate case (vector error correction model, VECM), offering the opportunity to detect more than one cointegration relationship in the context of a vector autoregression model (VAR).

Consider the vector autoregession (VAR) model of order k[3]

$$Y_t = A_1 Y_{t-1} + \dots + A_k Y_{t-k} + \varepsilon_t$$

where Y_t is a (nx1) vector of I(1) variables, such that ∇Y_t is stationary and $\varepsilon_t \sim N(0, \Sigma)$. The previous expression can be written in terms of the differenced vectors $\nabla Y_t = Y_t - Y_{t-1}$ and a lagged vector Y_{t-k}, getting the vector-error correction model (VECM):

$$\nabla Y_t = \Gamma_1 \nabla Y_{t-1} + \dots + \Gamma_{k-1} \nabla Y_{t-k-1} + \Pi Y_{t-k} + \varepsilon_t$$

Matrix Π has the information about the long-run relationships, the rank r of Π is known as the cointegration rank and is the number of cointegration relationships. The procedure of testing a hypothesis about r is known as Johansen's test.

The results of VECM may be biased if the time series are affected by a structural shift. Lütkepohl et al. (2004) proposed the following methodology for testing the cointegration rank of a VAR model affected by a structural shift in the level at unknown time. The proposed procedure consists in estimating the unknown location and size of the shift. Once the breakpoint is estimated, the data are adjusted accordingly. Finally, the Johansen's test is applied to the adjusted data in order to determine the number of cointegration relationships. Trenkler (2003) reported the critical values for cointegration tests with a prior adjustment for deterministic terms. Pfaff (2006) implemented this procedure in the URCA package written in R language.

The hypothesis test in this case is

H_0 (r_0): rank$(\Pi) = r_0$
H_1 (r_0): rank$(\Pi) > r_0$

[3] See Brocklebank and Dickey (2003), chap 5, for a more detailed description.

Table 5
Gregory and Hansen cointegration test.

τ statistic	Critical values			Breakpoint
	1%	5%	10%	
−5.57	−5.47	−4.95	−4.68	Obs 552, Feb 16, 2007
Estimated equation				
$SEP_t = -13.67 + 35.40\delta_{t\tau} + 24.04EDER_t - 48.52\delta_{t\tau}EDER_t$				

Notes:
The null hypothesis is no cointegration against cointegration in the presence of a possible regime shift. The location of the breakpoint is estimated sequentially, moving the break time around a central sample of the original values. For each break point, model 4 is estimated by OLS providing the residuals e_t, next the ADF test is applied to these residuals and the smallest value of the ADF statistics obtained across all possible break points is taken. This smallest value provides evidence against the null hypothesis and it has to be compared with the critical values tabulated in Gregory and Hansen (1996).
The test here is performed using model 4 proposed by the authors.
Model 4: Regime shift (C/S)
$y_t = \mu_1 + \mu_2\delta_{t\tau} + \beta_1 x_t + \delta_{t\tau}\beta_2 x_t + \varepsilon_t, \quad t = 1, \ldots, n$
with $\delta_{t\tau} = \begin{cases} 0 & if \quad t \le \tau \\ 1 & \text{if} \quad t > \tau \end{cases}$ where τ is the break time.

First of all, it is assumed that the vector process y_t is generated by the following model (inclusion of linear trend is optional):

$$y_t = \mu_0 + \mu_1 t + \mu_2\delta_{t\tau} + x_t \qquad t = 1, \ldots, n$$

with $\delta_{t\tau} = \begin{cases} 0 & \text{if} \quad t \le \tau \\ 1 & \text{if} \quad t > \tau \end{cases}$ where τ is the break time

Once the breakpoint τ is estimated, the data are adjusted for the estimated parameters according to:

$$\hat{x}_t = y_t - \hat{\mu}_0 + \hat{\mu}_1 t + \hat{\mu}_2\delta_{t\tau} \qquad t = 1, \ldots, n$$

After that, the usual test statistic based on the VECM can be obtained from

$$\nabla\hat{x}_t = \Gamma_1\nabla\hat{x}_{t-1} + \ldots + \Gamma_{k-1}\nabla\hat{x}_{t-k-1} + \Pi\hat{x}_{t-k} + \varepsilon_t$$

Table 6, Panel A, reports the results together with the critical values of the standard VECM model. The trace statistic, 24.649, exceeds the critical value at 1% level of significance, so $r = 0$ is rejected whereas this test does not reject the null hypothesis of $r \le 1$ at the 5% level of significance. This means that there is one cointegration relation or in other words, a single stationary linear combination exists in the long-run relationship between Spanish electricity prices (SEP) and USD/Euro exchange rate (EDER). Panel B of the same table displays the results of modified Johansen's trace test, applied to a VAR(4) model, with a shift in the level but no shift in the trend. The location of the breakpoint estimated is October 24, 2007, coinciding with the period in which oil price increases and USD suffered a big depreciation against Euro. Furthermore, the cointegration analysis in Panel C of this table shows that there is a cointegration relationship between SEP and OIL_DOL.

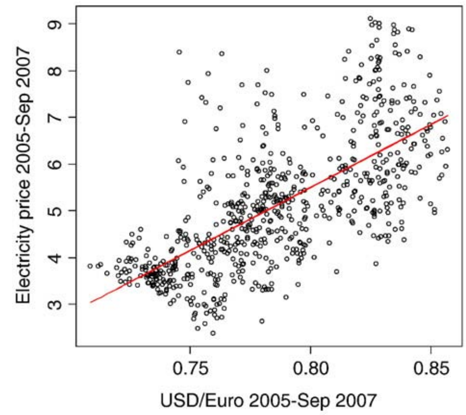

Fig. 4. Regression estimated for the period Jan 2005–Sept 2007.

Comparing the estimated cointegration relationships in Table 6, Panel B with the one estimated by Gregory and Hansen test (Table 5), we can conclude that although breakpoints estimated for both tests do not coincide, the cointegration vector estimated for both procedures, (1, −24.48) in Gregory and Hansen test and (1, −28.76) in the VECM with structural shift test, are very similar, suggesting stability of the long-run relationship between both variables. The differences detected between the results obtained for both tests can be explained because the VECM with structural shift test is applied to a VAR(4) model, which includes past evolution whereas the Gregory and Hansen test does not take into account past values.

3.2.1.4. Consistency of the results. Even though there is evidence of improvement with the three variables model, there is a nice empirical consistency of the two-variable model as we now illustrate. Only at a descriptive level and in order to test if the relationships estimated in the previous Sections (A.1 to A.3) are consistent, we decided to fit a linear regression for the data from January 2005 to September 2007 and to compare with the fitted model for data from January to March 2008, not used in this study (see Figs. 4 and 5). We didn't use the last quarter of 2007, a time in which the USD suffered another strong depreciation against the Euro and the increase in Spanish electricity prices was enormous, forced by the Europe Brent Spot Price, among

Table 6
Johansen's cointegration test using trace test statistics with two variables.

	Lags	H0 Rank = r	H1 Rank > r	Trace test statistics	5% Critical value	Estimated equation
Panel A: SEP and EDER						
SEP, EDER	4	0	0	24.649*	15.34	SEP = 15.64EDER
		1	1	0.040	3.84	
Panel B: SEP and EDER with breakpoint						
SEP, EDER	4	0	0	42.51*	12.28	SEP = 28.76EDER
		1	1	3.25	4.12	
Breakpoint: Oct 24, 2007						
Panel C: SEP and OIL_DOL						
SEP, OIL_DOL	4	0	0	19.322*	15.34	SEP = 0.026OIL_DOL
		1	1	0.778	3.84	

Notes:
The cointegrating equations assume that there is a drift in the model but not a trend when breakpoint is not detected. Lags are the number of lagged first differences in the VECM model and are determined using the AICC statistic. The null hypothesis is that there are r cointegration equations against the alternative that the number of the cointegrating equations is greater than r. An asterisk (*) means that the coefficient is significant at the 5% level. The estimated equation is the long-run relationship estimated when cointegration is detected.

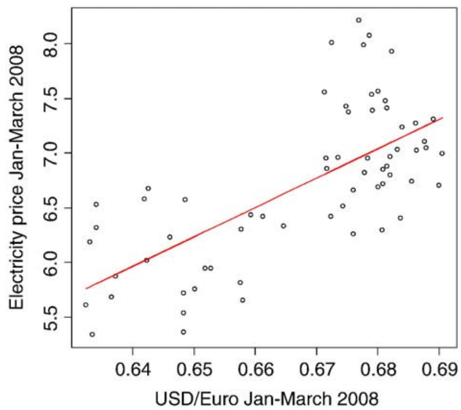

Fig. 5. Regression estimated for the period Jan 2008–March 2008.

others. The results are in Table 7, showing that the estimated slope is approximately the same in both sets of observations and the same conclusions are for the *R*-squared coefficient. This result gives us consistency with the previous ones obtained in the cointegration analysis, indicating that the relation between both variables remains constant, with exception of abrupt periods, as for example October–December 2007. (See Appendix A for the proof of consistency of regression estimated cointegrating relationships.)

3.2.2. Three-variable models

In this point, the two-variable VECM model with or without structural shift for the variables SEP and EDER is extended, adding the third variable of interest in this study, OIL_DOL. Table 8 displays the results of the error correction model. Panel A of Table 8 shows the results for the standard VECM model meanwhile the results for the model including structural shift are in Panel B of the same table. Comparing both panels, we observe that the coefficient associated to EDER has changed significantly with the introduction of the breakpoint. The breakpoint estimated in this case coincides with what is detected by means of the Zivot and Andrews test in the case of unit roots and it is the time when the big depreciation of dollar against Euro starts. However, the coefficients affecting the OIL_DOL variable do not change too much whether the model contains a breakpoint or not. All of these coincidences suggest a strong relationship between the Spanish electricity prices and the evolution of the exchange rate of the dollar against the Euro and a resulting vulnerability of the energy production.

The results of the different estimated vector-error correction models are not included, but they are available upon request.

3.3. Causality

Causality relationships are also studied in this paper. Granger (1969), in his seminal paper, proposed a test for detecting causality among two variables. This test allows us to distinguish whether lagged values of one variable (X) help explain variation in another (Y), but not vice-versa. The null hypothesis to test is that X does not "Granger-cause" Y and the rejection of the null can be interpreted that X "Granger-causes" Y.[4] The Granger-causality test has two main limitations: linearity and stationarity of the time series involved, and omitting the variables could detect spurious causal relationships. Another weakness is the sensitivity of this test to the choice of the lag length. There are other approaches in

Table 7
Regression estimated for both periods.

	Jan 2005–Sept 2007	Jan 2008–March 2008
Intercept	−16.04 (0.87)	−11.29 (2.41)
Slope	26.93 (1.10)	26.95 (3.60)
R^2	0.46	0.47

Note: St. Dev in parenthesis.

the case of non-linearity of the time series; see for example Dicks and Pancheko (2005) and Hristu-Varsakelis and Kyrtsou (2008). Engle and Granger (1987) stated the duality between cointegration and the vector-error correction model (VECM), showing that cointegration implies Granger-causality in at least one direction.

Results from Table 9 suggest that changes in oil prices can have an influence in the short run on the US/Euro exchange rate and on the Spanish electricity prices but not in the opposite sense. Those results are in agreement with those published by Sadorsky (1999). He points out that oil price movement can affect US economic variables but changes in US economic variables have little impact on oil prices.

4. Volatility estimated

Modeling volatility prices is critical to the understanding of financial markets, especially in the case of spots electricity prices. To investigate this, the relationship between the volatilities of Spanish electricity prices, USD/Euro and oil prices are analyzed. There are lots of papers on exchange rate volatility and the number of studies about commodity price volatility also is considerable, but the number of works analyzing the relationship between the three volatilities is not so large. Among others, Sadorsky (2001) concludes that movements of the Canada–US dollar exchange rate generated significant shocks in stock price returns for Canadian oil and gas companies. Regnier (2007) studies in depth the volatilities of a huge number of price series for the US and detects that 60% of crude series are significantly less price volatile than oil, but energy series fall in the range of the 20% of the series that are more volatile than oil. Recently, Park and Ratti (in press) have estimated the impact of oil price volatility on the stock markets in the US and 13 European countries and Cong et al. (2008) did it for the Chinese stock market. Zhang et al. (2008) analyze the influence of the USD/Euro exchange rate on crude oil prices for the period January 2000 to May 2005, concluding that volatility spillover between both markets is insignificant.

In order to study the relationship between the volatilities of Spanish electricity spot prices (SEP) USD/Euro exchange rate (EDER) and oil prices (OIL_DOL) we define volatility as the squared difference $V(t)=[Y(t)-Y(t-1)]^2$, then we use the $V(t)$ variable for SEP (V_SEP), then for EDER (V_EDER1000[5]) and then for OIL_DOL (V_OIL_DOL) as variables in a Granger Causality test. The results from this test will help us to understand the volatility transmissions between those variables. Fig. 6 shows that each time series presents periods of high volatility followed by periods of low volatility. This behaviour is known as volatility clustering. Volatility clustering can lead to excess kurtosis and implies that the series does not have a constant conditional variance. There is a leverage in the volatility of SEP and EDER around the same time in the sense that a period of high volatility occurs in both time series through the halves of 2006, coinciding with a previous period of one of the biggest depreciations of USD against Euro and the initial date of a new law in Spanish electricity market; after that, volatilities in both series continue decreasing, finishing with a slight increase at the end of 2007 coinciding with the increase of volatility of OIL_DOL.

The results from Table 10 indicate that there is a volatility transmission among VEDER1000 and V_SEP. Comparing these

[4] This test can be performed by means of the Wald test or using a likelihood test following an χ^2 distribution.

[5] The volatility of EDER is multiplied by 1000, in order to avoid numerical problems.

Table 8
Johansen's cointegration test using trace test statistics with three variables.

	Lags	H0 Rank = r	H1 Rank > r	Trace test statistics	5% Critical value	Estimated equation
Panel A: SEP,EDER and OIL_DOL						
SEP, EDER, OIL_DOL	4	0	0	37.315*	29.38	SEP = 24.064EDER + 0.05OIL_DOL
		1	1	8.909	15.34	
		2	2	0.005	3.84	
Panel B: SEP, EDER and OIL:DOL with breakpoint						
SEP, EDER, OIL_DOL	4	0	0	43.92*	24.28	SEP = 17.26EDER + 0.06OIL_DOL
		1	1	7.75	12.28	
		2	2	0.69	4.12	
Breakpoint: Feb 14, 2006						

Notes:
The cointegrating equations assume that there is a drift in the model but not a trend when breakpoint is not detected. Lags are the number of lagged first differences in the VECM model and are determined using the AICC statistic. The null hypothesis is that there are *r* cointegration equations against the alternative that the number of the cointegrating equations is greater than *r*. An asterisk (*) means that the coefficient is significant at the 5% level. The estimated equation is the long-run relationship estimated when cointegration is detected.

findings with those of the first difference variables (see Table 9), we can affirm that the volatility of USD/Euro exchange rate passes on to the volatility of electricity prices. This result differs from those obtained by the prices of those variables, in which the causality relationship from EDER to SEP was not significant. Similar results are obtained from the relationships between (EDER, OIL_DOL) and SEP, meanwhile for OIL_DOL and EDER variables the transmissions are both in level and variance and in the same sense, indicate that previous values of OIL_DOL level/volatilities affect future values of EDER level/volatilities.

5. Conclusions

The first finding in this study is that Spanish electricity spots prices, the USD/Euro exchange rate and oil prices are cointegrated; therefore there is a long-run equilibrium relationship between the three variables. Short-run relationships have been detected between oil prices and Spanish electricity prices and USD/Euro exchange rate in the sense that Spanish electricity prices and USD/Euro exchange rate are affected by oil prices in the short run. There is a transmission of volatility between USD/Euro exchange rate and oil prices to Spanish electricity prices; so although Spanish electricity prices are not affected in level by the movements of USD/Euro exchange rate, they are in volatility. Mohammadi (2009) studies the long-run relationships and short-term dynamics between fossil fuel and electricity prices for the US and detect that the long-run relationships between oil and electricity prices are not significant. One possible explanation of this contradiction between Mohammadi's results and our findings is the differences in the characteristics of both markets and the big external dependency of Spanish electricity market with fuel commodities. Our findings in relation with the short run movements of OIL_DOL and EDER coincide with those ones described in the work of Narayan et al. (2008) in the sense that previous values affects the evolution of the future values of EDER, both in level and volatility. Also our results about the relationships in level between OIL_DOL and EDER agree with the ones obtained by Chen and Chen (2007) in the sense that the authors pointed out: *"the ability of real oil prices to forecast future exchange rate returns"* however in our case we have not found a significant long-run relationship between oil prices and USD/Euro exchange rate.

The various tests used in this work did detect a breakpoint in the bivariate evolution of Spanish electricity spot prices and the USD/Euro exchange rate. There is no unanimity in the location of this breakpoint. The Gregory and Hansen test estimates it at February 2007 and the VECM model with structural shift at October 2007, but the common feature is that both locations are in the year 2007, a time at which Spanish electricity prices increased in coincidence with the increase in the prices of fossil fuels and the USD depreciation against Euro. Additionally, estimated volatilities for both series are also related. However, when the oil prices are introduced in the model, this breakpoint changes to June 2006, coinciding with the starting-point of the biggest depreciation of the dollar.

All these allow us to say that, because the Spanish electricity market is so dependent on this macroeconomic indicator, exchange rate fluctuations pose a possible risk for fossil fuel prices. This suggests that for countries like Spain, so strongly dependent on importing fossil fuels, the resort to renewable energy sources in conditions acceptable for a non monopolist market could substantially increase its energy security.

For future work, two topics remain open. The first is related to the findings from the detection of breaks in the time series. The existence of these break states reveals their nonlinear behavior. In this case, the approaches proposed by Dicks and Pancheko (2005) and Hristu-

Table 9
Granger-causality in first differences variables.

Causality	Lags	Wald statistic	df	*p*_value
∇EDER → ∇SEP	4	3.28	4	0.512
∇SEP → ∇ EDER	4	7.84	4	0.098
∇OIL_DOL → ∇SEP	4	9.45	4	0.049*
∇SEP → ∇OIL_DOL	4	1.38	4	0.848
∇OIL_DOL → ∇EDER	1	6.47	1	0.011*
∇EDER → ∇OIL_DOL	1	0.51	1	0.476
(∇EDER, ∇OIL_DOL) → ∇SEP	4	11.60	8	0.170

Notes:
The symbol (∇) is equivalent to (1-B), indicating a first difference in the appropriate variable. A → B means that lagged values of A give information about the future of B. Lags are the number of lagged variables in the VAR model and are determined using the AICC statistic. The null hypothesis is that A does not cause B. An asterisk (*) means that the statistic is significant at the 5% level, allowing rejection of the null hypothesis.

Table 10
Granger-Causality Wald test in volatility series.

Causality	Lags	Wald statistic	df	*p*_value
V_EDER1000 → V_SEP	3	12.23	3	0.007*
V_SEP → V_EDER1000	3	2.29	3	0.514
V_OIL_DOL → V_SEP	5	3.64	5	0.603
V_SEP → V_OIL_DOL	5	2.93	5	0.711
V_OIL_DOL → V_EDER1000	1	8.56	1	0.0034*
V_EDER1000 → V_OIL_DOL	1	0.01	1	0.908
(V_EDER1000, V_OIL_DOL) → V_SEP	3	16.46	6	0.012*

Notes:
A → B means that the lagged values of A give information about the future of B. Lags are the number of lagged variables in the VAR model and are determined using the AICC statistic. Wald statistic follows a χ^2_ν distribution with ν degrees of freedom (df). The null hypothesis is that A does not cause B. An asterisk (*) means that the Wald statistic is significant at the 5% level, allowing rejection of the null hypothesis.

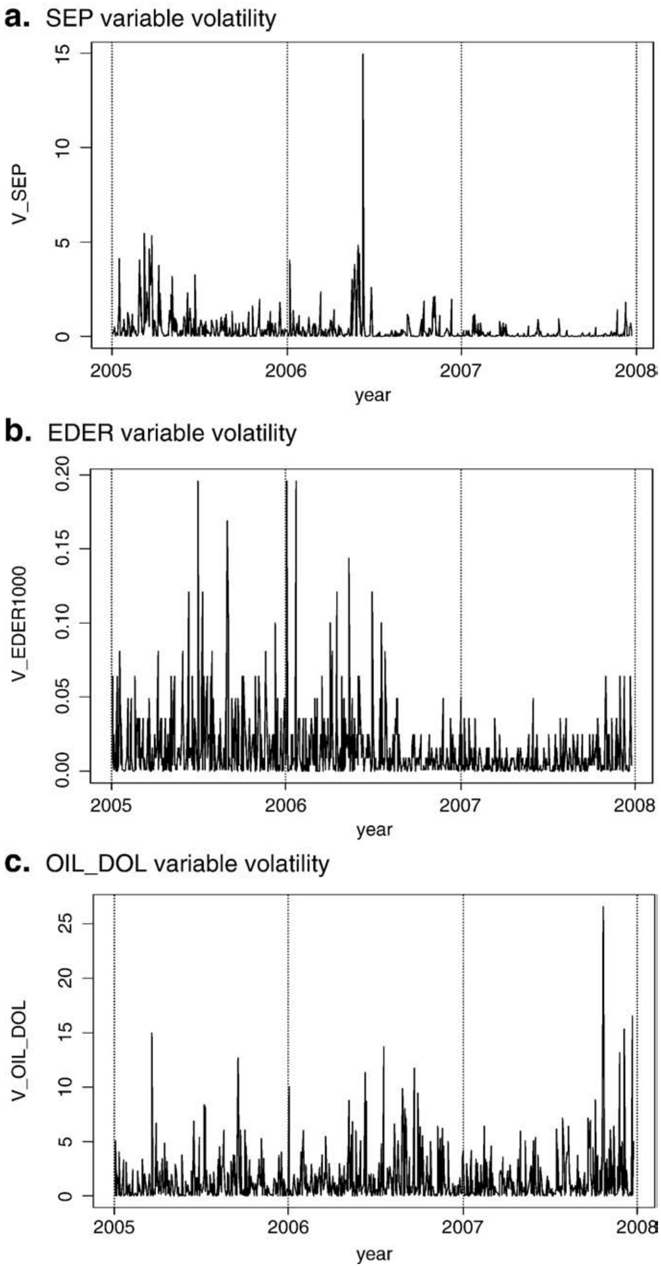

Fig. 6. Volatilities. *Notes*: We define volatility as squared difference $V(t)=[Y(t)-Y(t-1)]^2$. The volatility of EDER is multiplied by 1000, in order to avoid numerical problems. SEP is the Spanish electricity spot price, EDER is the USD/Euro exchange rate and OIL_DOL is the Europe Brent spot price in dollars.

Varsakelis and Kyrtsou (2008) for non-linear casual relationships will be analyzed. The results from those approaches will be contrasted with those obtained in this work. The second is related to the long-run and short-run relationships detected in the present work. Our idea is to enrich the knowledge by analyzing the dependencies of the Spanish electricity prices with other macroeconomic indicators that could affect its evolution; as for example the cost of renewable energies and the future cost of CO_2 allowances. Currently renewable energies have financial support from the Spanish government but if there is a change in policy, cancelling or decreasing this financial support, the cost of these energies could revert to the consumers, and in this case a balance between using renewables and other energies would have to take into account the maintenance of electricity at a reasonable price.

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Appendix A. Consistency of regression estimated cointegrating relationships

If Y_t and X_t are I(1) and cointegrated, then there is a shared trend, let us call this W_t, that is a unit root process with $\sum_t W_t^2 / n^2 = O_p(1)$. The bivariate (X, Y) series can be represented as

$$Y_t = \beta_1 W_t + Z_{1t}$$
$$X_t = \beta_2 W_t + Z_{2t}$$

where each Z_{it} is stationary and thus has sum of squares of order $1/n$. The sum of cross products between W and Z must be of the order of the geometric mean of the orders of W and Z, namely $n^{-3/2}$. Notice from above that $\beta_2 Y_t - \beta_1 X_t = \beta_2(Y_t - (\beta_1/\beta_2)X_t) = \beta_1 Z_{2t} - \beta_2 Z_{1t}$ which is stationary so the cointegrating vector is $(1, -\beta_1/\beta_2)$. Using the orders above, we can see that

$$\sum_t Y_t X_t / n^2 = \beta_1\beta_2 \sum_t W_t^2 / n^2 + O_b(1/\sqrt{n})$$
$$\sum_t X_t^2 / n^2 = \beta_2^2 \sum_t W_t^2 / n^2 + O_b(1/\sqrt{n})$$

so the regression of Y on X has a coefficient that converges to β_1/β_2 and thus produces the correct cointegrating vector asymptotically (that is, the regression estimator is consistent but not necessarily efficient). This is the essential feature of the Engle–Granger method, in that the residuals from the regression would, based on an equation above, be approximately $Z_{1t} - (\beta_2/\beta_1)Z_{2t}$ so Engle and Granger are counting on the consistency when they do a unit root test on these residuals to test for cointegration. Of course if we do not have a cointegration but just two independent I(1) series, then we have inconsistency as the W series that goes with Y would not be the same as the W that goes with X (so to speak) and so would not drop out of the regression residuals.

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