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Granger Causality Test and Chow Breakpoint Test on The Romanian Day Ahead Electricity Market

Daniel Ciuiu[a]*, Marina Bãdileanu[b], Luminita Izabell Georgescu[c]

[a]*Technical University of Civil Engineering Bucharest, Bd. Lacul Tei No. 124, Bucharest 020396, Romania*
[b]*Romanian Institute for Economic Forecasting,Calea 13 Septembrie No. 13, Bucharest 050711, Romania*
[c]*National Institute of Economic Research, Calea 13 Septembrie No. 13, Bucharest 050711, Romania*

Abstract

In this paper we will apply the causality Granger test between the closure prices on Romanian day ahead energy markets and different primary energy sources production (coal, hydrocarbons, nuclear, wind and hydro energy). We will apply also the Chow breakpoint test for the prices independently, and for the prices expressed in terms of above energy sources.
From practical reasons (because we have obtained seasonal components for the involved time series) we will generalize the Granger causality test such that we take into account the seasonal components.

Keywords: Granger causality test; Chow breakpoint test; energy market; sources of energy;

1. Introduction

A time series X_t has the decomposition (Popescu, 2000) in three parts: the seasonal component, the trend and the stationary part. The elimination of the seasonal component can be done by seasonal differentiation $\left(\Delta_s X_t = X_t - X_{t-s}\right)$, and the elimination of trend can be done by differentiation $\left(\Delta X_t = X_t - X_{t-1}\right)$. The seasonal differentiation is done as many times we need until the seasonal component vanishes, and next we perform the

* Corresponding author. Tel.: +0-4021-683-61-52.
E-mail address: dciuiu@yahoo.com

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differentiation until the time series becomes stationary. There exist also other methods to eliminate the seasonal component and the trend, as the method of moving average and the exponential smooth method (Jula, 2003; Popescu, 2000). In this paper we use the differentiation method, because in the Granger causality test it is used the order of integration (the number of differentiations until the time series becomes stationary).

The Granger causality test checks if a time series is a cause for another one (Jula, 2003; Voineagu et al., 2007). First, we identify the maximum order of integration for the two time series, N, and second we express the linear regression of Y_t in terms of $Y_{t-1},\ldots, Y_{t-N}$, and $X_{t-1},\ldots, X_{t-N}$. Denoting by RSS_r and RSS_n the sum of squares for the above regression considering all the coefficients of X_i zero and without these constraints, and by T the number of observations, we compute next the F-statistics as follows:

$$F = \frac{RSS_r - RSS_n}{RSS_n} \cdot \frac{T-2N-1}{N}, \qquad (1)$$

which has the Snedecor-Fisher distribution with N and T-$2N$-1 degrees of freedom. Therefore we reject the fact that X is a Granger cause for Y if and only if $F < F_{N,T-2N-1}(\varepsilon)$, where $F_{N,T-2N-1}(\varepsilon)$ is the quantile of error ε for the Snedecor-Fisher distribution.

Thus the hypothesis that we want to test, both ways, is that the energy prices (daily average, off-peak and peak) are determined by the previous values of the energy quantities and reciprocally.

Because in the case of classical version of Granger causality test (Granger, 1980 and 1988) we take into account the orders of differentiation of the two time series X_t and Y_t, it arise the problem of testing for initial values of time series, and in affirmative case for the time series obtained by differentiation $(\Delta X_t = X_t - X_{t-1})$, the null hypothesis of non- stationarity (obviously against the alternative hypothesis of stationarity of tested time series). Therefore, for each of the two time series we test the stationarity, and, if the tested time series is non-stationary, we differentiate the time series, and next we repeat the test until we obtain by successive differentiations a stationary time series.

In literature, for testing the non-stationarity, we take into account that if the time series X_t is stationary, then ΔX_t does not depend on X_{t-1} (Jula, 2003). The unit root tests have been built starting from that mentioned above by some linear regression models for which the dependent variable is ΔX_t, and one of the explanatory variables is X_{t-1}. The test is reduced to check if the coefficient of X_{t-1} is zero. We mention here the Dickey-Fuller test and the ADF (Augmented Dickey-Fuller) test. The difference between these tests consists in the fact that for the first case the only explanatory variable is X_{t-1}, and for the ADF test there exist also the explanatory variables ΔX_{t-1}, ΔX_{t-2} and so on.

For the Chow breakpoint test, in order to see if there are any breakpoints in the data time series, we estimate first the F statistics (Chow, .1960; Jula, 2003; Kurach and Stelmach, 2014). Then, we compare this statistics with the quintile of the Snedecor-Fisher distribution with number of degrees of freedom computed as in the works previously mentioned. We can compute also the error (1-the value of the cumulative distribution function) (Getzner, Glatzer and Neck, 2001; Dijkgraaf and Gradus, 2003).

In this case the hypothesis is that the time series for the energy prices and quantities are without breakpoints.

2. The Granger and Chow tests

The Granger causality tests in the classical form (Dospinescu and Mitrofan, 2013; Jula and Jula, 2013) involves only differentiation, and does not take into account the seasonal components, as we have for prices in energy market and energy production from different sources. As personal contribution, we consider for linear regressions all the coefficients of $(1-B^s)^{n_s}$ and $(1-B)^d$ for seasonal and non-seasonal differentiation. Of course, n_s and d are maximum for X and Y. For the Chow test we use the EViews software. The necessity of generalization of Granger causality test such that we take into account the seasonal components arise from practical reasons. As we will see at the application, only three time series out of eight have not seasonal components: the other five have each five seasons, that yields a weekly seasonality, because for each week of the considered time horizon we have data for five days (lack Fridays and Saturdays).

For guessing the number of seasons for a time series we study first the correlogram: if the number of seasons is *s*, the autocorrelation function has the period *s* and it has local maximum for *k* multiple of *s*. We do this after each seasonal differentiation until this property is no more fulfilled. In this case we have not unit root tests asd in the case of non-seasonal differentiation, hence we use the pure intuition.

Even for non-stationarity of a time series without seasonal component there exist unit root tests, we can see from correlogram if the time series is stationary: in this case the autocorrelation function tends to zero.

As in the case of finding the number of seasons, the eventually breakpoints that are tested next by the Chow breakpoint test are also found by intuition: after stationarising we perform the differentiation and the outliers can be breakpoints. We cannot apply the Chauvenet test for identifying outliers in a sample from a population normal distributed, from the same reasons that we cannot apply the Student test to check stationarity.

3. Application

In order to determine the influence of the different kinds of energy resources utilized for electricity generation on its prices, statistical data were analyzed. The data refer to the average daily energy installed capacities (www.transelectrica.ro) and the day ahead electricity prices for the 24 months of the 2012 and 2013 years (January-December 2012 and January – July 2013), totaling 373 observations. (www.opcom.ro).

The primary data base consists of the following indicators:

- The average installed capacity of the coal based generation units (MW);
- The average installed capacity of the hydrocarbon based generation units (MW);
- The average installed capacity of the nuclear generation units (MW);
- The average installed capacity of the wind farms (MW);
- The average installed capacity of the hydro energy units (MW);
- The electricity daily average prices determined for the 1^{00}-24^{00} hours (lei/MWh);
- The electricity average prices resulted from the spot market transactions in peak hours 7^{00}-22^{00} (lei/MWh);
- The electricity average prices resulted from the spot market transactions in off peak hours 1^{00}-6^{00} and 23^{00}-24^{00} (lei/MWh).

The analysis was conducted for the 2012 and 2013 years, daily from Mondays to Thursdays and on Sundays. Fridays and Saturdays were not considered because there is no data available for these days. First we have to stationarize the involved eight time series. For the daily average prices we have the following correlogram (Table 1):

Table 1: The correlogram of the daily average electricity prices

<table>
<tr><th>Autocorrelation</th><th>Partial Correlation</th><th></th><th>AC</th><th>PAC</th><th>Q-Stat</th><th>Prob</th></tr>
<tr><td>.|***** |</td><td>.|***** |</td><td>1</td><td>0.607</td><td>0.607</td><td>138.65</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|** |</td><td>2</td><td>0.493</td><td>0.197</td><td>230.34</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|* |</td><td>3</td><td>0.462</td><td>0.168</td><td>311.14</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|** |</td><td>4</td><td>0.485</td><td>0.197</td><td>400.41</td><td>0.000</td></tr>
<tr><td>.|***** |</td><td>.|*** |</td><td>5</td><td>0.662</td><td>0.452</td><td>566.79</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>**|. |</td><td>6</td><td>0.452</td><td>-0.199</td><td>644.76</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|. |</td><td>7</td><td>0.412</td><td>0.042</td><td>709.58</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|. |</td><td>8</td><td>0.393</td><td>0.012</td><td>768.68</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|. |</td><td>9</td><td>0.406</td><td>0.044</td><td>832.15</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|* |</td><td>10</td><td>0.558</td><td>0.182</td><td>951.96</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>*|. |</td><td>11</td><td>0.353</td><td>-0.178</td><td>999.99</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>12</td><td>0.320</td><td>-0.013</td><td>1039.7</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|* |</td><td>13</td><td>0.341</td><td>0.076</td><td>1085.0</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|* |</td><td>14</td><td>0.373</td><td>0.066</td><td>1139.2</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|* |</td><td>15</td><td>0.516</td><td>0.138</td><td>1243.4</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>*|. |</td><td>16</td><td>0.334</td><td>-0.065</td><td>1287.1</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>17</td><td>0.318</td><td>0.031</td><td>1327.0</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>18</td><td>0.312</td><td>-0.029</td><td>1365.2</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>19</td><td>0.314</td><td>-0.029</td><td>1404.2</td><td>0.000</td></tr>
<tr><td>.|**** |</td><td>.|* |</td><td>20</td><td>0.487</td><td>0.175</td><td>1498.2</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>*|. |</td><td>21</td><td>0.301</td><td>-0.107</td><td>1534.3</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>22</td><td>0.270</td><td>-0.040</td><td>1563.3</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>23</td><td>0.257</td><td>-0.036</td><td>1589.8</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>24</td><td>0.281</td><td>0.042</td><td>1621.4</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|. |</td><td>25</td><td>0.423</td><td>0.049</td><td>1693.3</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>26</td><td>0.250</td><td>-0.047</td><td>1718.5</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>27</td><td>0.217</td><td>-0.045</td><td>1737.6</td><td>0.000</td></tr>
<tr><td>.|* |</td><td>.|. |</td><td>28</td><td>0.193</td><td>-0.053</td><td>1752.8</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>29</td><td>0.218</td><td>0.019</td><td>1772.1</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|. |</td><td>30</td><td>0.364</td><td>0.050</td><td>1826.2</td><td>0.000</td></tr>
<tr><td>.|** |</td><td>.|. |</td><td>31</td><td>0.214</td><td>-0.007</td><td>1844.9</td><td>0.000</td></tr>
<tr><td>.|* |</td><td>.|. |</td><td>32</td><td>0.180</td><td>-0.021</td><td>1858.2</td><td>0.000</td></tr>
<tr><td>.|* |</td><td>.|. |</td><td>33</td><td>0.177</td><td>0.019</td><td>1871.1</td><td>0.000</td></tr>
<tr><td>.|* |</td><td>.|. |</td><td>34</td><td>0.190</td><td>-0.027</td><td>1886.0</td><td>0.000</td></tr>
<tr><td>.|*** |</td><td>.|* |</td><td>35</td><td>0.374</td><td>0.173</td><td>1943.8</td><td>0.000</td></tr>
</table>

.|** |	.|. |	36	0.208	-0.054	1961.8	0.000

and the following graphics (figures 1a, 1b and 2):

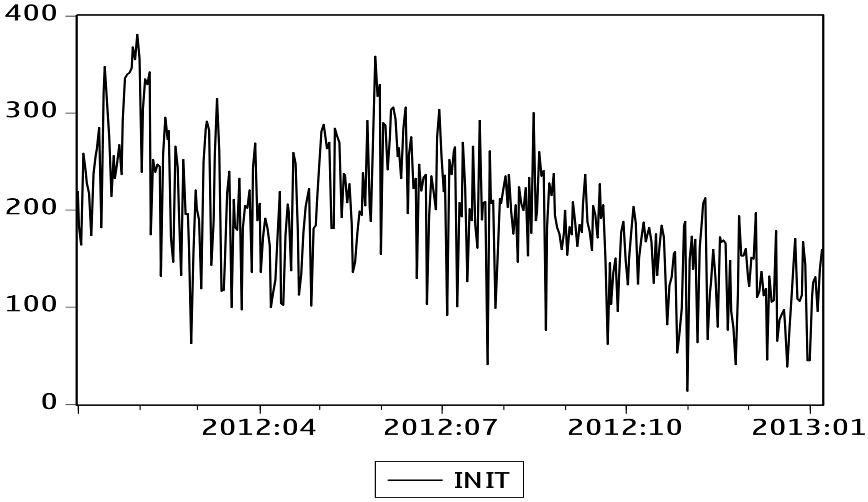

Fig.1a: Initial daily average prices time series

According the correlogram, there are five seasonal components. There we have to apply the seasonal differentiation (Popescu, 2000). For the obtained time series, we apply the ADF (augmented Dickey-Fuller) unit root test, in order to check the time series' stationarity.

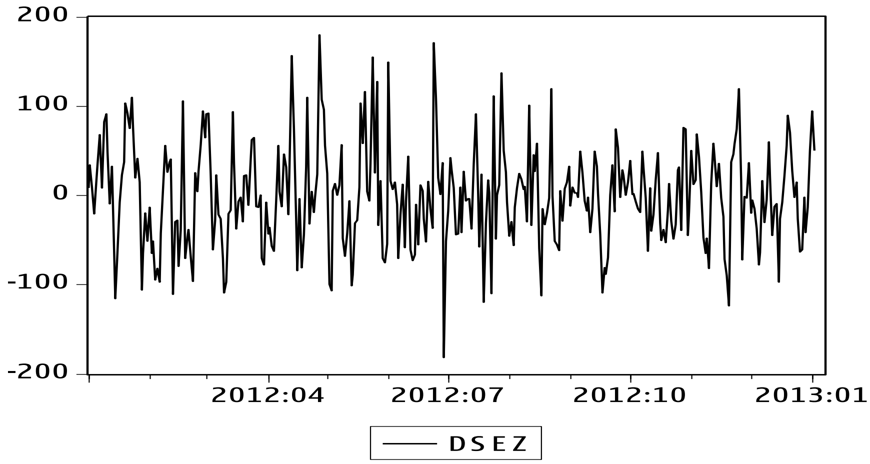

Fig 1b: Initial daily average prices time series

We obtain

$$\Delta Y_t = -1.2097456 - 0.925942 Y_{t-1} + 0.292266 \Delta Y_{t-1} + 0.299978 \Delta Y_{t-2} + 0.319242 \Delta Y_{t-3} + 0.356356 \Delta Y_{t-4}$$

The ADF statistics is -12.03986, which is less than the quantile of 1% error, -3.4503. therefore, the obtained time series is stationary.

The same results were obtained for peak and off-peak load prices, and the energy generated on coal and hydro energy. The other time series are non-seasonal, respectively the hydrocarbons which is I(1), and the nuclear and wind generation series are stationary.

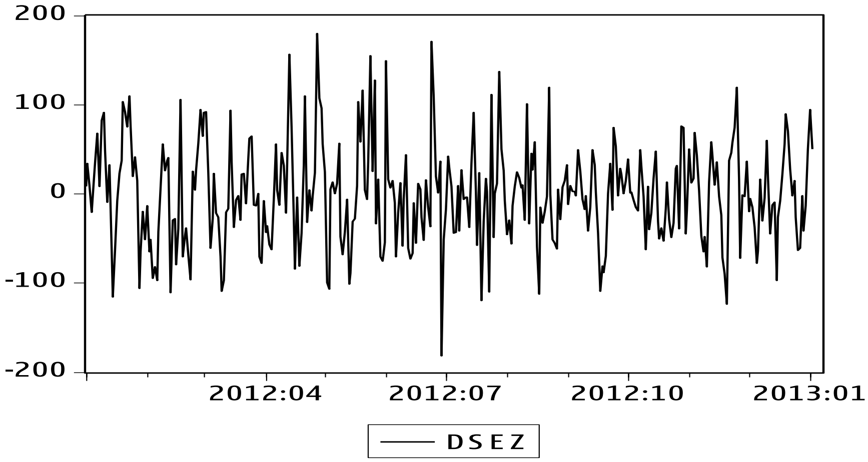

Fig. 2: The seasonal differentiation of the daily average prices time series

For the Granger causality test in all cases except those regarding the hydrocarbons the involved terms of linear regressions are Y_{t-5} and X_{t-5}. Due to the fact that hydrocarbons are I(1), we have to add for these situations the terms Y_{t-1} and X_{t-1} .

Table 2 - Results for the Granger causality test

Variables	Equation Y(X)	Equation X(Y)	F_Y	F_X
Average price by coal generation	$Y_t=32.65+ 0.43Y_{t-5}+ 0.03 X_{t-5}$	$X_t=356.2+0.81 X_{t-5}+0.51 Y_{t-5}$	31.15	**1.26**
Average price by hydrocarbons generation	$Y_t=24.17+0.38Y_{t-1}+ 0.47Y_{t-5} -0.015X_{t-1} + 0.02 X_{t-5}$	$X_t=1.82+0.66X_{t-1}+ 0.26X_{t-5}-0.27Y_{t-1} + 0.65Y_{t-5}$	2.09	**7.73**
Average price by nuclear generation	$Y_t=21.03+ 0.65Y_{t-5}+ 0.03 X_{t-5}$	$X_t=472.3+0.57 X_{t-5}+0.44 Y_{t-5}$	10.55	**44.07**
Average price by wind generation	$Y_t=44.83+ 0.71Y_{t-5}+ 0.026 X_{t-5}$	$X_t=381.20+0.19 X_{t-5}-0.39 Y_{t-5}$	6.93	**149.65**
Average price by hydro generation	$Y_t=94.56+ 0.63Y_{t-5} -0.015X_{t-5}$	$X_t=541.9+0.83X_{t-5} -1.30Y_{t-5}$	11.04	**33.67**
Peak price by coal generation	$Y_t=29.5+ 0.48Y_{t-5}+ 0.034X_{t-5}$	$X_t=361.26+0.79X_{t-5}+ 0.56 Y_{t-5}$	29.39	**2.02**

Peak price by hydrocarbons generation	$Y_t=24.7+0.3Y_{t-1}+0.56Y_{t-5}-0.02X_{t-1}+0.02X_{t-5}$	$X_t=-3.74+0.66X_{t-1}+0.25X_{t-5}-0.24Y_{t-1}+0.62Y_{t-5}$	2.49	**10.39**
Peak price by nuclear generation	$Y_t=16.6+0.69Y_{t-5}+0.04X_{t-5}$	$X_t=475.9+0.56X_{t-5}+0.42Y_{t-5}$	12.12	**46.37**
Peak price by wind generation	$Y_t=41.6+0.75Y_{t-5}+0.033X_{t-5}$	$X_t=355.5+0.20X_{t-5}-0.24Y_{t-5}$	10.66	**148**
Peak price by hydro generation	$Y_t=103.5+0.66Y_{t-5}-0.018X_{t-5}$	$X_t=530+0.82X_{t-5}-1.04Y_{t-5}$	14.49	**29.78**
Off-Peak price by coal generation	$Y_t=41.03+0.36Y_{t-5}+0.018X_{t-5}$	$X_t=366.2+0.85X_{t-5}-0.152Y_{t-5}$	35	**0.11**
Off-Peak price by hydrocarbons generation	$Y_t=28.7+0.56Y_{t-1}+0.21Y_{t-5}-0.001X_{t-1}+0.003X_{t-5}$	$X_t=31.8+0.65X_{t-1}+0.29X_{t-5}-0.06Y_{t-1}+0.25Y_{t-5}$	0.09	**0.72**
Off-Peak price by nuclear generation	$Y_t=41.2+0.49Y_{t-5}+0.02X_{t-5}$	$X_t=491.8+0.59X_{t-5}+0.31Y_{t-5}$	19.65	**37.48**
Off-Peak price by wind generation	$Y_t=66.7+0.49Y_{t-5}+0.0003X_{t-5}$	$X_t=426+0.16X_{t-5}-0.83Y_{t-5}$	15.34	**155.71**
Off-Peak price by hydro generation	**$Y_t=76.5+0.48Y_{t-5}-0.005X_{t-5}$**	**$X_t=463.3+0.85X_{t-5}-1.61Y_{t-5}$**	**17.21**	**33.77**

In order to accept the Granger causality for 1% error we have to compare the statistics with the 1% quantile 6.66. In order to reject the Granger causality for 10% error we have to compare the statistics with the 10% quintile 2.74. These quintiles are for situations that do not involve the hydrocarbons where the above quintiles are 4.53 and 2.4 (in the first case the numbers of freedom degrees are 1and 365 and in the second case 2 and 363).

It results a sole exempt this is the off peak prices for the hydrocarbons (there is no Granger causality in this situation).

The coal generation X_1 presents a Granger causality for all three envisaged prices (with a 1% error).

For the hydrocarbons, the average and peak prices are Granger causes (with a 1% error) for the generated quantities.

In none of the situations the prices are not Granger causes (error 10%) for the coal quantities (x1) and neither the hydrocarbons quantities are not Granger causes for the prices.

In the other cases (nuclear, wind and hydro) the causes benefit from reciprocity.

For the Chow test we need to determine the ARMA structure for every time series (the eight ones composed from three price time series and five quantities time series divided by energy resource), as follows:

Table 3 - Results for the Chow breakpoint test

Time series	ARMA equation	Degrees of freedom	F statistics	Error	Breakpoints
Average daily prices	$Y_t=0.4Y_{t-1}+A_t$	2; 365	6.82	0.001234	In 152 and 209
Peak prices	$Y_t=0.37Y_{t-1}+A_t$	2; 365	7.42	0.000695	In 152 and 209
Off-peak prices	$Y_t=0.42Y_{t-1}+A_t$	3; 364	4.04	0.007638	In 68, 223, 325
Coal	$Y_t=0.74Y_{t-1}+At+0.01A_{t-1}+0.04A_{t-2}+0.03A_{t-3}+0.1A_{t-4}-0.75A_{t-5}$	24;338	7.83	Less than $5x10^{-7}$	79,152,225,243

Hydrocarbons	$Y_t=A_t-0.39A_{t-1}-0.26A_{t-2}$	6;364	3.50	0.00224	In 128,180,265
Nuclear	$Y_t=0.87Y_{t-1}+A_t$	6; 366	7.18	Less than $5x10^{-7}$	84,132,215,234,291,347
Wind	$Y_t=0.99Y_{t-1}+A_t-0.65A_{t-1}-0.28A_{t-2}$	12; 358	4.55	10^{-6}	138,237,288,302
Hydro	$Y_t=0.5Y_{t-1}+A_t$	3; 364	4.74	0.002946	142,225,330

The breakpoints are considered according to the difference between the present and previous values of the obtained stationary time series. The following graphic depicts the case of the daily average price (figure 3)

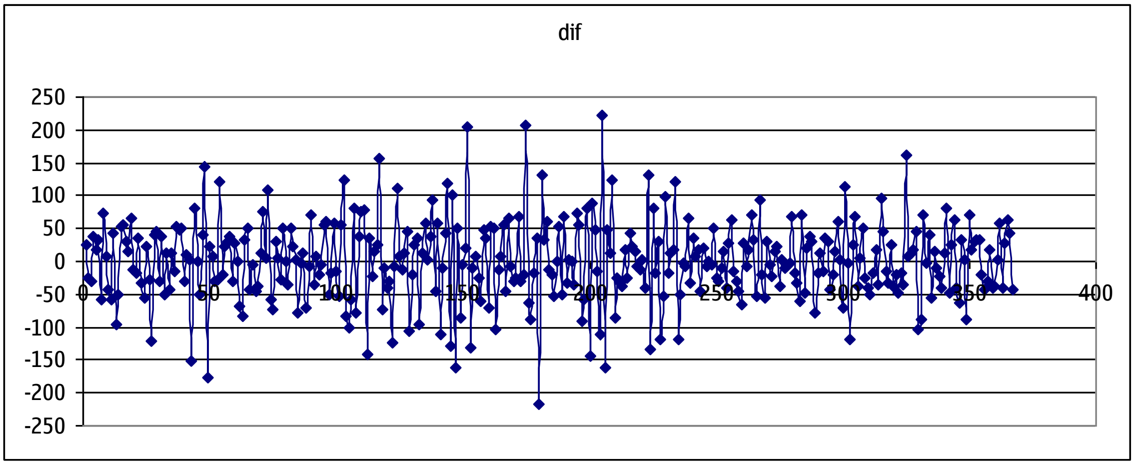

Fig 3. Daily average prices difference after stationarization

Results that, according to our calculations, there are no time series without breakpoints. The previous table shows the breakpoints for each of these time series.

4. Conclusions

- For coal, the closure price on the day ahead market does not influence the traded quantity. The coal quantities time series is seasonal, in other words, the today prices are influenced by the same day of the previous week;
- In the case of hydrocarbons, for the analysed period, the contribution to the electricity production traded on the spot market was low due to the existence of a huge number of regulated contracts. This could be the explanation for the fact that the quantities did not influence significantly, at that time, the prices (the statistics F_y=2,09<4,53). In the meantime, the number of the regulated contracts decreased a lot, the hydrocarbons electricity producers being forces to offer higher quantities on the day ahead market. Therefore, a radical change is possible for the last period. From the computations, the neither hydrocarbons time series is nor stationary, neither seasonal. From our analysis, results that the average prices and the peak prices are Granger causes for the hydrocarbon quantities and therefore the today's hydrocarbons quantity depends on the previous week's price and the yesterday's one.
- Regarding the nuclear units, they do not influence directly the closure prices of the day ahead market because they are not traded on the spot market, this type of electricity generation being under a priority regime. The prices are influenced when one of the two nuclear units is under repair. In this case, the Granger causality is reciprocal;

- The wind contribution to the electricity generation structure on different primary energy resources is the main determinant for the spot market prices volatility, fact that was demonstrated also in one of our previous papers (Ciuiu, Bădileanu, Georgescu, 2014). We demonstrated the existence of an important number of outlier prices in the analyzed time period. Also, from the present computations where the $F_x$statistics has a very high value, we can conclude that the wind units indeed have an important role in determining the functioning of the day ahead market. The wind energy prices influence a great deal the traded quantities. Another situation is registered in the case of the $F_y$statistics which shows a reduced influence of the previous week's analogue day quantity. This does not exclude an important negative correlation with the volume of the present traded quantity. This determinations result also from the fact that the wind energy operators are not interested in the prices obtained on the spot market, their main objective being to obtain the green certificates granted for every generated MW. To this situation contributes also the substantial growth of the percentage of the wind energy in the energy generation structure the same time with the preferential regime that this type of energy benefits from as a prioritary production.
- As regards the hydro energy, all three cases considered (average, peak and off-peak prices) the conducted computations generated negative correlations between prices and quantities, keeping in mind the seasonal influences.

The general conclusions are:

- the first tested hypothesis - the energy prices (daily average, off-peak and peak) are determined by the previous values of the energy quantities and reciprocally - was not verified for all cases (in the off-peak prices and quantities for hydrocarbons there are no correlations, the prices do not influence the coal quantities in none of the three situations, and the quantities of hydrocarbons do not influence the average and peak prices)
- the second tested hypothesis- the time series for the energy prices and quantities are without breakpoints is rejected in all the eight situations. The most numerous breakpoints are registered in the nuclear case.

Takind into account these results, our intent for the future researches is to apply the transfer function model in order to see the influences of the energy traded quantities on energy prices and to build, based on the existing literature, intervention models for the Chow test case.

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