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TESTING FOR INFORMATIONAL EFFICIENCY ON THE POLISH ENERGY MARKET

Abstract: In this paper authors made a revision of the chosen statistical tests verifying the hypothesis of the weak-form market efficiency and then these methods were applied to the Polish Power Exchange in the period 2007–2010. Unit root test verifying the assumption about stationarity of analyzed time series were conducted before testing the weak market efficiency. In the empirical studies the variance ratio test, the runs test and the long-range dependences tests were used and the results of above-mentioned tests showed that daily electricity price returns in Polish Power Exchange from January 2007 to December 2010 do not have the random nature.

Keywords: Efficient Market Hypothesis, variance ratio test, unit root test, R/S analysis, energy market.

1. Introduction

The Polish Power Exchange implements and modifies the market mechanism of energy price establishing through, among others, ensuring its users access to market information and introducing transparent and unified for all users terms of concluding business transactions. According to the rules of the market gambling energy pricing on the exchange should be a balancing price for bid and ask prices, submitted by both buyers and sellers. Moreover, energy prices established on the exchange should be used as commonly valid referential prices in evaluating activities associated with energy production, sales or purchase. Thus, it is worth checking if the mechanism of energy pricing implemented on the Polish Power Exchange guarantees that all market participants have the same access to all available market information, which is immediately and fully discounted in the energy prices. If this is true, then market participants cannot obtain greater than average profits from the transactions conducted on the exchange, on condition that they are indifferent to the risk and formulate rational expectation in respect of energy price. The proper fulfillment of the above mentioned functions is associated with the notion of market information efficiency. The outline of Efficient Market Hypothesis (EMH) was presented in the work of Louis Bachelier (1900) for the first time, and was later developed and described by Eugene Fama [1965, 1970] and Paul Samuelson [1965]. Knowledge about information efficiency of energy markets is useful in market risk management process and in developing investment strategies. In practice studies of the market efficiency are conducted with reference to a particular information set, which can comprise:

– historical quotations of the given goods,
– all public available information describing the situation on the market,
– all information on the given market and its surroundings, including confidential information.

It should also be noted that quantitative tools helpful in making investment decisions can change subject to the efficiency form of the given market. Participants in a weakly efficient market, who perform only a technical analysis, would not expect any additional profit. Fundamental analysis as well as technical analysis are useless tools in a market that is only half-strong efficient. However, if the market is strongly efficient, than all efforts to acquire confidential information make no sense.

Thus, when making a decision about buying or selling energy, priced on the market characterized by information efficiency, investors must only know its most current price, which also includes information on the past periods. The lack of dependence in the price series in the short and long run reflects their random character, that is why it is assumed that the process of energy price shaping on the power market is the random walk process. The assumption about the random walk of prices is used to test weak market information efficiency. When there are no grounds to reject the random walk hypothesis, there are no grounds to reject the hypothesis of a weak market efficiency either. However, rejecting the random walk hypothesis does not constitute the basis to reject the weak market efficiency hypothesis. In such a situation additional tests of weak market efficiency need to be applied, for example, analyzing investment strategy scenarios using technical analysis tools. It is worth to wonder if all kinds of statistical and econometric analysis provide for a possibility to develop investment strategies that would regularly generate profit above average.

This paper is focused on the verification of the market efficiency hypothesis in its weak form. Thus, if prices of energy change in a random manner (such a situation exists in a weakly efficient market), return above average will not be achieved by analysing historical prices. This means that the issue of modelling and forecasting energy prices in a weakly efficient market is groundless.

Verification of the weak-form efficient market hypothesis can be done with the use of the random walk assumption. The following aspects are tested then:

1) if shaping prices of the particular assets is well described by the random walk process,

2) if the rates of return from the investment into particular assets show the white noise quality.

The aim of the paper is on the one hand to review the chosen statistical tests verifying the hypothesis of weak market information efficiency, and on the other hand to check, with the use of the above mentioned tests, whether the process of generating energy prices on the Polish Power Exchange confirms the assumptions of the random walk. In addition, unit root test verifying the assumption about stationarity of analyzed time series were conducted before testing the weak market efficiency.

2. The random walk hypothesis – most important properties and relationships with the EMH

The simplest model describing changes of financial instruments prices is the random walk with drift, which in discrete time is described by the following equation [Weron, Weron 1998]:

$$P_t = \mu + P_{t-1} + \varepsilon_t, \qquad \varepsilon_t \sim IID(0, \sigma^2) \tag{1}$$

where: P_t – financial instrument price at the moment t,
μ – constant term in the model, called the drift, expressing average change of price from period to period,
ε_t – "white noise" effects, determined as residuals of the model, estimated on the basis of empirical data.

The white noise process represents random interference being a sequence of random variables of independent identical distribution with zero expected value and finite, fixed variances. In case of such a purely random process, the correlation function values equal zero for every lag. Process ε_t, in particular, is called Gaussian white noise if random variables distributions are normal.

The literature of the subject mentions three types of the random walk process [Campbell, Lo, MacKinlay 1997]:

a) random walk of the first kind (Random Walk 1) – financial instrument price increments are independent random values of the same probability distribution;

b) random walk of the second kind (Random Walk 2) – financial instrument price increments are independent, however, they may differ in probability distribution depending on the period chosen for analysis of market functioning;

c) random walk of the third kind (Random Walk 3) – financial instrument price increments are serially uncorrelated, however, nonlinear dependences that may occur between them allow to predict their future value.

The presented Brownian motion process constitutes the basic theoretical model describing price shaping on exchange markets due to its basic qualities: continuity of almost all realizations, stationary and independent increments. The arithmetic version of the Brownian motion is used to model economic processes which take both positive and negative values. Their value growths, however, have normal distribution increments with the variance growing linearly in time. Due to the fact that prices of assets cannot take negative values, their modeling allows for geometrical version of Brownian motion [Hull 1999]:

$$\frac{dP_t}{P_t} = \mu dt + \sigma dW_t \tag{2}$$

$$dW_t = \varepsilon_t \sqrt{dt} \tag{3}$$

where: $dW_t = W_{t+dt} - W_t$ – random value with the distribution N (0, dt),

μ – process drift expressing expected price change,

σ – process parameter representing its volatility,

ε_t – sequence of independent random variables with identical distribution N (0, 1).

The lack of dependences in the price series in the short and long run reflects their random nature. The Random Walk Hypothesis assumes that the process of asset price shaping is a random walk process. The following statistical tests and methods are used to verify RWH, and at the same time to study weak market efficiency [Włodarczyk 2009; Campbell, Lo, MacKinlay 1997]:

– the variance ratio tests (Random Walk 1, Random Walk 3),
– filter rules (Random Walk 2),
– technical analysis (Random Walk 2),
– the autocorrelation coefficients tests (Random Walk 3),
– the runs tests (Random Walk 1),
– the unit root tests (Random Walk 3),
– the tests for long-range dependences (Random Walk 3).

Although the variance ratio tests and autocorrelation coefficients tests are often criticized in the literature of the subject, they are often used to verify the random walk hypothesis [Wang, Yang 2010; Dima, Miloş 2009]. The chosen tests used to verify the randomness of energy price changes are described below.

3. The variance ratio test

The variance ratio test uses the random walk quality that consists in the occurrence of linear dependence between the variance and the length of the time period in which it is measured. If prices of assets are subject to random walk then the returns are so called white noise, and thus variables of identical and independent distributions. Therefore, it ensues from the additiveness quality of the logarithmic returns that the variance of the price increments sum in the period t and $t + 1$ should be twice bigger than the variance of the price increment in the t period [Papla 2003]:

$$VR(q) = \frac{\sigma^2[R_t(q)]}{q\sigma^2(R_t]}, \tag{4}$$

where: $R_t = \ln\left(\frac{P_t}{P_{t-1}}\right)$ – one-period logarithmic returns,

$R_t(q) = R_t + R_{t-1} + R_{t-2} + ... + R_{t-q+1}$ – q-period logarithmic returns,

$VR(q)$ – q order variance ratio,

$\sigma^2(R_t)$ – variance of one-period returns,

$\sigma^2[R_t(q)]$ – variance of q-period returns.

Assuming that the null hypothesis is true, where it is assumed that the process of asset price shaping is the random walk one, the second order variance ratio should equal one, so as there are no grounds to reject this hypothesis.

In the case when the assumption of random character of returns is not fulfilled, the increase (decrease) of the asset's price at the moment t influences the increase (decrease) of the price at the moment t + 1, and the variance of the sum of these increments is twice bigger (smaller) than the variance of the increment from the t period and it grows faster (slower) than linearly. In order to prove the random walk hypothesis it is not enough to confirm the assumption of insignificance of the first order autocorrelation dependences in the analyzed time series. It is also necessary to exclude the existence of higher order autocorrelation dependences. In the case of the higher order it is required to check the returns that are more than one period away from each other [Grotowski, Wyroba 2004]:

$$V\hat{R}(q) \cong 1 + 2\sum_{k=1}^{q-1}\left(1 - \frac{k}{q}\right)\hat{\rho}(k), \tag{5}$$

where: $\rho(k)$ – k order autocorrelation coefficient.

The choice of the variance estimator in the variance ratio test is conditioned by the assumed random walk model. The random walk of the first kind is presented first.

The test assumes that the returns are not only independent, but they also have identical distribution, which leads to the following modification of the q order variance ratio formula [Campbell, Lo, MacKinlay 1997]:

$$V\hat{R}(q) = \frac{\hat{\sigma}^2(q)}{\hat{\sigma}^2(1)}, \tag{6}$$

where:

$$\hat{\sigma}^2(1) = \frac{1}{nq-1}\sum_{k=1}^{nq}\left(R_k - R_{k-1} - \hat{\mu}\right)^{,}, \tag{7}$$

$$\hat{\sigma}^2(q) = \frac{1}{m}\sum_{k=q}^{nq}\left(R_k - R_{k-q} - q\hat{\mu}\right)^2, \tag{8}$$

$$m = q(nq - q + 1)\left(1 - \frac{q}{nq}\right), \tag{9}$$

$$\hat{\mu} = \frac{1}{nq}\sum_{k=1}^{nq}(R_k - R_{k-1}), \tag{10}$$

where: $V\hat{R}(q)$ – estimator of q order variance ratio,

$\hat{\sigma}^2(1)$ – estimator of one-period returns variance,

$\hat{\sigma}^2(q)$ – estimator of q-period returns variance,

qn – length of analyzed period.

$VR(q)$ statistic was normalized, so as to in large samples it was approximated by the normal distribution [Campbell, Lo, MacKinlay 1997]:

$$Z(q) = \frac{VR(q) - 1}{[\phi(q)]^{\frac{1}{2}}}, \tag{11}$$

where:

$$\phi(q) = \frac{2(2q-1)(q-1)}{3q(nq)}, \tag{12}$$

where: $Z(q)$ – normalized ratio $N(0,1)$.

Comparing real variance ratio values to proper theoretical values, compatible with the assumed model of price random walk, will enable verifying the significance of the difference between both variances on condition that the variables are subject to normal distribution. Assuming that the null hypothesis is true, the critical region of the test was defined by the relation:

$$P(|Z(q)| > u_\alpha) = 1 - \alpha. \tag{13}$$

Then the null hypothesis refers to the Random Walk 3 model as it assumes that the price increments are serially uncorrelated. Assuming the heteroscedasticity of returns and using the representation of the variance ratio in the form of weighted sum of autocorrelation coefficients, the variance of which is determined by (5), the following formulas can be obtained [Cheong 2009]:

$$Z^*(q) = \frac{\sqrt{nq}(VR(q) - 1)}{\sqrt{\phi^*(q)}}, \qquad N(0,1) \tag{14}$$

$$\phi^*(q) = 4\sum_{j=1}^{q-1}\left[1-\frac{k}{q}\right]^2 \hat{\delta}_k\,, \tag{15}$$

$$\hat{\delta}_k = \frac{\sum_{j=k+1}^{nq}\left(R_t - R_{t-1} - \hat{\mu}\right)^2\left(R_{j-k} - R_{j-k-1} - \hat{\mu}\right)^2}{\left[\sum_{j=1}^{nq}\left(R_j - R_{j-1} - \hat{\mu}\right)^2\right]^2}, \tag{16}$$

where: Z^* – test statistic with asymptotic normal distribution $N(0,1)$,

$\varphi^*(q)$ – the asymptotic variance of q order variance ratio estimator,

$\hat{\delta}_k$ – the asymptotic variance of k order autocorrelation coefficient estimator.

The critical region is determined similarly to the test of random walk of the first kind, that is according to the relation (13).

4. The runs test

The runs test (Wald-Wolfowitz test), first used by Fama [1965], is conducted in order to check if the returns of the investment in the particular asset take a random form. The idea of the test is to compare the number of series in the empirical distribution of returns with the theoretical number of series, which is characteristic of the random walk. The series is a return sequence of the same sign occurring successively one after another. The runs tests can be applied for two- and three-element case. Choosing the two-element version of this test, "1" symbol should be assigned if the return is positive or equals zero, and "–1" symbol should be assigned if the return is negative. In this case the lack of the asset price change is treated as an advantageous situation for the investor. However, application of the three-element run test consists in the division of the analyzed returns series into: negative returns marked as "–1", zero returns marked "0", and positive returns, which are assigned "1" symbol.

In the null hypothesis it is assumed that the returns from the investment into a particular asset are generated by the Random Walk 1 model while the alternative hypothesis indicates the non-random nature of the price changes. The check of the test is U test statistic of standardized normal distribution and is defined by the following formula [Witkowska, Matuszewska, Kompa 2008]:

$$U = \frac{K - E(K)}{\sqrt{\sigma^2(K)}}, \tag{17}$$

where: K – empirical distribution of the series,

$E(\mathrm{K})$ – expected number of series.

For the test based on two elements of the series, the following formula is used to determine the expected value:

$$E(K) = \frac{2n_1 n_2 + n}{n}, \tag{18}$$

where: n – number of elements in the checked return series,
n_1 – number of "1" symbols, namely the number of returns characteristic of the non-decreasing trend,
n_2 – number of "–1" symbols, namely number of returns generated by the decreasing trend.

However, for the test based on three elements of the series the following relation is used to determine the expected value:

$$E(K) = n + 1 - \frac{\sum_{j=1}^{3} n_j^2}{n}, \tag{19}$$

where: n – number of elements in the checked return series,
n_j – number of "–1", "0" and "1" symbols.

Similarly the variance for the number of $\sigma^2(K)$ series is determined depending on the accepted at the beginning of the specification number of signs, on the basis of the formulas:

$$\sigma^2(K) = \frac{2n_1 n_2 (2n_1 n_2 - n)}{(n-1)n^2} \tag{20}$$

for the test based on two elements of the series:

$$\sigma^2(K) = \frac{\sum_{j=1}^{3} n_j^2 \left(\sum_{j=1}^{3} n_j^2 + n + n^2 \right) - 2n \sum_{j=1}^{3} n_j^3 - n^3}{n^3 - n}. \tag{21}$$

The test statistic has asymptotic normal distribution, on condition that the minimum number of the elements in the individual series must include at least 20 observations.

Thus, the critical value region of the test is determined by the following relation:

$$P(|U| > u_\alpha) = 1 - \alpha. \tag{22}$$

The popularity of this test is connected with the possibility of finding both linear and nonlinear dependences occurring in the return series of the investment in a particular asset [Domański, Pruska 2000]. Moreover, the runs test is included into the group of non-parametric tests and thus, it does not require accepting the assumption of its return distribution normality.

5. The Hurst Exponent Test

The analysis of the rescaled range, that is R/S analysis, proposed by Hurst [1951] and modified in the Lo's work [1991], is in historical approach the first test applied to check long memory. While testing economic time series Mandelbrot [Mandelbrot 1972] noticed that if past returns influence future returns, that is short or long memory occur, then the value of the rescaled range is significantly greater than in the case of the processes characterized by lack of memory. The null hypothesis refers to the Random Walk 3 model as it assumes that the price increments are serially uncorrelated. In this method the Q_n statistic is estimated, which is an index created from the range of cumulated deviations of the time series values from their mean [Laurent 2009]:

$$Q_n = \left[[\max_{1\le k\le n} \sum_{j=1}^{k} (R_j - \overline{R}_n)] - [\min_{1\le k\le n} \sum_{j=1}^{k} (R_j - \overline{R}_n)] \right], \tag{23}$$

where: Q_n – scaled range in k-elements subsample.

Next, on the basis of the statistic defined by the relation (23) Mandelbrot statistic is determined, which defines a range rescaled by the standard deviation:

$$\frac{R}{S} = \frac{1}{\sqrt{n} \cdot s_n} Q_n, \tag{24}$$

where: $\frac{R}{S}$ – Mandelbrot statistic for scaled distance,

s_n – standard deviation for the n-elements time series.

Assuming that the null hypothesis is true, the $\frac{R}{S}$ statistic has asymptotically similar distribution to the Brownian bridge range determined on the unit range.

This test was used to check weak condition of energy market efficiency by, among others, Weron [2002], and Weron, Przybyłowicz [2000].

6. Empirical results of verifying the random walk assumption on Polish Power Exchange

The paper presents the results of the studies concerning weak information efficiency of the exchange energy market in Poland. The studies were conducted on the basis of daily average energy prices in the period 1.01.2007 – 31.12.2010 listed on the Day

Ahead Market of the Polish Power Exchange. The Day Ahead Market is the physical spot market for energy which enables:

– initial balancing of contractual positions for market participants,
– indirect evaluation of the electric power companies value,
– generating investment signals in the range of building new production power.

The aim of the empirical studies conducted in this part is to check whether the energy prices established on the Polish Power Exchange are generated by the Random Walk process. Verifying this hypothesis may prove useful to determine if energy prices established on the Day Ahead Market (DAM) instantly and fully reflect all historical information made available to the market participants, and if the prices are correctly established.

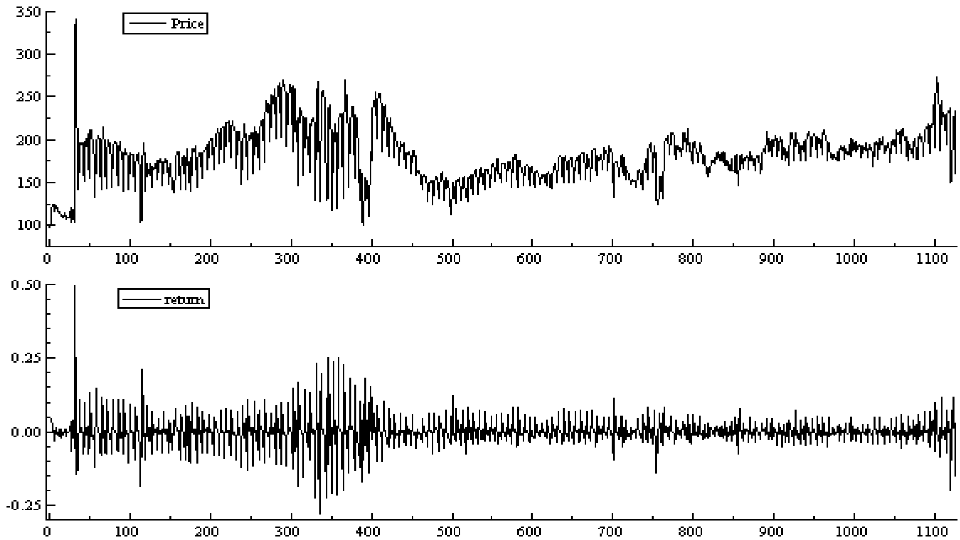

Figure 1. The daily average energy prices (top panel) and its rates of return (bottom panel) on Day-Ahead Market of Polish Power Exchange in the period 1.01.2007 – 31.12.2010

Source: own work.

The basic statistics, that is: mean and standard deviation were determined for energy price logarithmical returns, established on the Polish Power Exchange (see Table 1a); stationarity tests (KPSS, ADF, S-P)[1] were conducted; fractional integration parameters for returns and square returns of energy prices were evaluated with the method proposed by Geweke and Porter-Hudak (GPH) [Geweke, Porter-

[1] Particular tests for time series stationarity were presented in the work of Laurent [2009].

-Hudak 1983], and Robinson [1995] in order to verify long and short memory effect in the conditional mean and conditional variance of the process (see Table 1b).[2]

Table 1a. Basic statistics for rates of return of energy prices

Statistic	Logarithmic rate of return of energy prices
Average	0.0001918
Standard deviation	0.051396
Minimum	–0.27972
Maximum	0.49567

Source: own calculations in G@RCH.

Table 1b. Unit root test and long memory test for rates of return of energy

Test	Statistic
KPSS /KPSS trend	0.0182202/0.00758833
ADF	–28.123
GPH	–0.313047 [0.0000]
SCHMIDT-PHILLIPS (S-P)	–20.0702
Robinson	–0.401949 [0.0000]
GPH – squares of returns	0.164877 [0.0000]
Robinson – squares of returns	0.162599 [0.0000]

In parentheses is the p-value. KPSS test critical values: 0.739 (1%), 0.463 (5%), 0.347 (10%); KPSS with trend: 0.216(1%), 0.146 (5%), 0.119 (10%). critical values of SCHMIDT-PHILLIPS test: –3.56 (1%), –3.02 (5%), –2.75 (10%). Critical values of ADF test: –3.96104 (1%), –3.41127 (5%), –3.12748 (10%).

Source: own calculations in G@RCH.

Analyzing the results presented in Table 1b the stationarity of the energy price logarithmical returns in Poland can be concluded on the basis of each conducted stationarity test. Estimates of fractional integration parameter for the Geweke and Porter-Hudak method, as well as the Robinson method show the occurrence of a long-term dependence effect both in levels and squares of energy price returns.

The variance ratio test, the runs test and the Hurst exponent test were used to verify RWH, which were applied for energy price logarithmical returns. In accordance with the quality of the white noise process used in the present test, that the variance of the price increments sum in the period t and $t - 1$ should be twice bigger than the variance of the price increment in the t period.

For every discussed lag order the p-value in Table 2 is smaller than 0.05, therefore the null hypothesis should be rejected in favour of the alternative hypothesis which assumes that energy price changes on the Polish Power Exchange in the period 01.01.2007 – 31.12.2010 do not show a random nature.

[2] Detailed description of both procedures of fractional integration parameter estimation can be found in the work of Baillie's [Baillie 1996].

Table 2. The results of variance ratio test assuming Random Walk 3

Lag order	Logarithmic rate of return of energy prices		
	VR(*q*)	*Z**(*q*)	*p*-value
2	0.80121	–3.90764	0.00009
3	0.62444	–5.10362	0.00000
4	0.48912	–5.70925	0.00000
5	0.36985	–6.18510	0.00000
6	0.26709	–6.52095	0.00000
7	0.15454	–6.91558	0.00000
8	0.23180	–5.80060	0.00000
9	0.25115	–5.24199	0.00000
10	0.23858	–4.98081	0.00000
11	0.22584	–4.77415	0.00000
12	0.20529	–4.65791	0.00000
13	0.17480	–4.62387	0.00000
14	0.12203	–4.72208	0.00000
15	0.15825	–4.35865	0.00001
16	0.17072	–4.14366	0.00003
17	0.16705	–4.02503	0.00006
18	0.15708	–3.94763	0.00008
19	0.14390	–3.89288	0.00010
20	0.12648	–3.86584	0.00011
21	0.09425	–3.90720	0.00009
22	0.11926	–3.70746	0.00021

Source: own calculations in G@RCH.

Another test procedure applied in market efficiency studies conducted by Fama [1965] also verifies if the energy price returns depend on historical changes. The series of consecutive elements were defined by assigning them symbol "1" if the return was positive, symbol "0" for zero returns and "–1" symbol if the return was negative. On the basis of the determined sign series for returns, the empirical value of the test statistic was determined (see Table 3).

Table 3. Runs test for the logarithmic rates of return on energy prices

Statistic of runs test	*p*-value
–1.47499	[0.1402150]

Source: own calculations in G@RCH.

As the *p*-value in Table 3 is greater than 0.05 there are no grounds to reject the null hypothesis showing the randomness of energy price logarithmical returns changes in Poland in the studied time period.

The last stage of the empirical analysis comprises determining the rescaled range according to the procedure proposed by Hurst and Mandelbrot (23)–(24). In the test procedure the null hypothesis of serially uncorrelated energy price changes in Poland will be verified. Table 4 includes empirical values of R/S statistic and the value range that does not give any basis for rejecting the null hypothesis.

Table 4. Hurst and Mandelbrot test for logarithmic rates of return of energy prices

R/S statistic	Range for not reject the null hypothesis
0.34644	90%: [0.861, 1.747] 95%: [0.809, 1.862] 99%: [0.721, 2.098]

Source: own calculations in G@RCH.

On significance levels: 0.01, 0.05, 0.1 the null hypothesis must be rejected, that means that significant dependences in the energy price return series occurred in the studied time period in Poland. The results of the abovementioned test were additionally supplemented by calculating Lo's statistic (1994), through the elimination of the short-term influence of dependences which potentially occur in the time period enabling verification of long-term dependences.

Table 5. Lo correction for the logarithmic rates of return of energy prices

Lag order	Lo statistic
1	0.385277
2	0.436104
3	0.492172
4	0.565621
5	0.66423
6	0.867478
7	0.712681
8	0.685339
9	0.702593
10	0.721657
11	0.756815
12	0.817687
13	0.969765
14	0.858414
15	0.828584
16	0.837659
17	0.862501
18	0.900536
19	0.957394
20	1.0958
21	0.982871
22	0.953242
90	1.52007
180	1.66339

Source: own calculations in G@RCH.

It is worth noticing that the elimination of short-term dependences increases the value of the rescaled range. This is caused by negative, in most cases, autocorrelation coefficient values with orders higher than the first one. The test conducted by Lo does not determine unequivocally the random nature of energy price returns shaping. On the 0.05 significance level, Lo's determined statistic for the lags up to the 12th order is statistically significant, which indicates a rejection of the null hypothesis about the serial uncorrelation of the energy price returns. However, for the lags of at least 12 there are no grounds to reject the null hypothesis, which means that the energy price returns in the tested period were serially uncorrelated.

7. Conclusions

The random walk hypothesis assumes that energy prices on energy exchanges are established according to the principle of balancing demand and supply of the particular asset and are generated by the random walk process. If the above-mentioned hypothesis is true, then the price returns do not show either short-term or long-term dependences. They are characterized by linear variance growth and identical probability of energy price increase and decrease. In order to test the above-mentioned dependences the authors of the paper used:

– the unit roots test,
– the GPH test and Robinson test for long-term dependences occurrence,
– the variance ratio test assuming Random Walk 3.

The studies conducted for the energy prices listed on the Polish Power Exchange in the period 1.01.2007 – 31.12.2010 showed that:

– stationarity of the series of logarithmic energy price returns in Poland can be concluded on the basis of every conducted stationarity test;
– estimates of fractional integration parameter for the Geweke and Porter-Hudak method, as well as the Robinson method show the occurrence of the long-term dependence effect both in levels and squares of energy price returns;
– according to the variance ratio test, energy price returns do not have a random nature, and their variance is not the linear time function;
– according to the results of the runs test, logarithmic energy price returns behave in a random manner;
– the Hurst index test indicates a relevant correlation of energy price returns, Lo's statistic in turn does not determine unequivocally the random nature of the energy price shaping.

The studies were also conducted with modified energy prices according to the formula, where logarithmic returns were subjected to the standardization procedure and then the VR method was used to verify short-term and long-term dependences occurrence in the transformed time series. The results obtained were not different from the ones presented in the paper. Future studies will concern the removal of the ARCH effect from the energy price return series, and the next application of the variance ratio test for modified series, in accordance with the suggestion in Laurent's work [Laurent 2009].

The Polish Power Exchange has been functioning for only 10 years and methods of its efficiency testing are still being developed. Taking into consideration the fact that confirmation of the random walk hypothesis means also confirming the information efficiency hypothesis, and rejecting RWH does not constitute the basis for EMH rejecting, on the basis of the conducted studies the efficiency of Polish Power Exchange cannot be unequivocally determined. More and more often the literature of the subject contains examples of applying detrended fluctuation analysis (DFA) to verify the information efficiency hypothesis of the developed energy markets. This tool will be used in future studies devoted to the information efficiency of the Polish Power Exchange.

References

Baillie R.T. (1996), Long memory processes and fractional integration in econometrics, *Journal of Econometrics*, Vol. 73, pp. 5–59.

Campbell J.Y., Lo A.W., MacKinlay A.C. (1997), *The Econometrics of Financial Markets*, Princeton University Press, Princeton.

Cheong C.W. (2009), A variance ratio test on random walk in energy spot markets, *Journal of Quantitative Economics*, Vol. 8, No. 1, pp. 105–117.

Dima B., Miloş L.R. (2009), Testing the efficiency market hypothesis for the Romanian stock market, *Annales Universitatis Apulensis Series Oeconomica*, Vol. 11, No. 1, pp. 402–415.

Domański C., Pruska K. (2000), *Nieklasyczne metody statystyczne*, PWE, Warszawa.

Fama E.F. (1970), Efficient capital markets: A review of theory and empirical work, *Journal of Finance*, Vol. 25, No. 2, pp. 383–417.

Fama E.F. (1965), The behavior of stock market prices, Journal of Business, Vol. 38, No. 1, pp. 34–105.

Geweke J., Porter-Hudak S. (1983), The estimation and application of long memory time series models, *Journal of Time Series Analysis*, Vol. 4, pp. 221–238.

Grotowski M., Wyroba K. (2004), Efektywność informacyjna polskiego rynku walutowego – analiza wstępna, *Bank i Kredyt*, Vol. 35, No. 1, pp. 65–79.

Hull J. (1999), *Kontrakty terminowe i opcje. Wprowadzenie*, WIG-Press, Warszawa.

Hurst H. (1951), Long term storage capacity of reservoirs, *Transactions of the American Society of Civil Engineers*, Vol. 116, pp. 770–799.

Laurent S. (2009), *Estimating and Forecasting ARCH Model Using G@RCH™ 6*, Timberlake Consultants, London.

Lo A.W. (1991), Long-term memory in stock market prices, *Econometrica*, Vol. 59, pp. 1279–1313.

Mandelbrot B.B. (1972), Statistical methodology for nonperiodic cycles from covariance to R/S analysis, *Annals of Economic and Social Measurement*, Vol. 1, pp. 259–290.

Papla D. (2003), *Związki pomiędzy zmianami poziomu efektywności informacyjnej i wielkości spółek na GPW w Warszawie*, Dynamiczne Modele Ekonometryczne, Toruń.

Robinson P.M. (1995), Log-periodogram regression of time series, with long range dependence, *Annals of Statistics*, Vol. 23, pp. 1630–1661.

Samuelson P.A. (1965), Proof that properly anticipated prices fluctuate randomly, *Industrial Management Review*, Vol. 6, No. 2, pp. 41–49.

Wang T., Yang J. (2010), Nonlinearity and intraday efficiency tests on energy futures markets, *Energy Economics*, Vol. 32, No. 2, pp. 496–503.

Weron A., Weron R. (1998), *Inżynieria finansowa*, Wydawnictwa Naukowo-Techniczne, Warszawa.
Weron R. (2002), Estimating long-range dependence: Finite sample properties and confidence intervals, *Physica A*, Vol. 312, pp. 285–299.
Weron R., Przybyłowicz B. (2000), Hurst analysis of electricity price dynamics, *Physica A*, Vol. 283, pp. 462–468.
Witkowska D., Matuszewska A., Kompa K. (2008), *Wprowadzenie do ekonometrii dynamicznej i finansowej*, SGGW, Warszawa.
Włodarczyk A. (2009), *Modele cen instrumentów finansowych a efektywność rynku kapitałowego*, [in:] A. Mesjasz-Lech (red.), *Nowoczesne instrumenty zarządzania*, Sekcja Wydawnictw Wydziału Zarządzania Politechniki Częstochowskiej, Częstochowa.

TESTOWANIE EFEKTYWNOŚCI INFORMACYJNEJ NA POLSKIM RYNKU ENERGII

Streszczenie: W niniejszym artykule dokonano przeglądu wybranych testów statystycznych weryfikujących hipotezę efektywności rynku w formie słabej, a następnie zastosowano opisane metody do weryfikacji tejże hipotezy na Towarowej Giełdzie Energii w Polsce w okresie 2007–2010. Testy pierwiastków jednostkowych, weryfikujące założenie o stacjonarności analizowanych szeregów czasowych, przeprowadzono przed testowaniem słabej efektywności rynku. W badaniach empirycznych wykorzystano test ilorazu wariancji, test serii znakowych oraz testy na występowanie długoterminowych zależności w szeregach czasowych. Wyniki wymienionych powyżej testów wskazują, iż dzienne ceny energii elektrycznej na Towarowej Giełdzie Energii w Polsce, od stycznia 2007 do grudnia 2010, nie zmieniały się w sposób czysto losowy.

Słowa kluczowe: Hipoteza Efektywności Rynku, test ilorazu wiarygodności, test pierwiastka jednostkowego, analiza R/S, rynek energii.