PRACE NAUKOWE UNIWERSYTETU EKONOMICZNEGO WE WROCŁAWIU
RESEARCH PAPERS OF WROCLAW UNIVERSITY OF ECONOMICS AND BUSINESS

2020, vol. 64, nr 1

ISSN 1899-3192
e-ISSN 2392-0041

Marek Kołatka
University of Gdansk
e-mail: marek.kolatka@ug.edu.pl
ORCID: 0000-0002-7037-3457

TESTING THE ADAPTIVE MARKET HYPOTHESIS ON THE WIG STOCK INDEX: 1994-2019

TESTOWANIE HIPOTEZY RYNKÓW ADAPTACYJNYCH DLA INDEKSU GIEŁDOWEGO WIG: 1994-2019

DOI: 10.15611/pn.2020.1.11
JEL Classification: G14

Summary: The adaptive market hypothesis (AMH) is gaining recognition in the world of science because it coherently and logically reconciles the opinions of representatives of the neoclassical school and of behaviourists. The article assesses the reasons for the application of this hypothesis in the context of the Polish stock market. The aim of the article is to examine the level of predictability of return rates of the main Polish stock exchange index. For this purpose, daily logarithmic return rates were applied from the WIG index from October 1994 to December 2019. Moreover, the occurrence between them of a linear dependence (an autocorrelation test) and non-linear dependence (BDS test) was verified for two-year rolling-window framework. The results obtained confirm the cyclical variability of the level of efficiency for the Polish stock market, which complies with the implications of the adaptive market hypothesis.

Keywords: adaptive market hypothesis (AMH), market efficiency, return predictability.

Streszczenie: Hipoteza rynków adaptacyjnych (AMH) ma coraz większe uznanie w świecie naukowym, gdyż w sposób spójny i logiczny godzi poglądy przedstawicieli szkoły neoklasycznej oraz behawiorystów. W artykule oceniono zasadność stosowania tej hipotezy w kontekście polskiego rynku akcji. Celem artykułu jest zbadanie poziomu przewidywalności stóp zwrotu głównego polskiego indeksu giełdowego. Wykorzystano dzienne logarytmiczne stopy zwrotu z indeksu WIG od października 1994 r. do grudnia 2019 r. i dla dwuletnich ruchomych podokresów zweryfikowano występowanie między nimi zależności liniowych (test autokorelacji) i nieliniowych (test BDS). Otrzymane wyniki potwierdzają cykliczną zmienność poziomu efektywności dla polskiego rynku akcji, co jest zgodne z implikacjami hipotezy rynków adaptacyjnych.

Słowa kluczowe: hipoteza rynków adaptacyjnych, efektywność rynku, przewidywalność stóp zwrotu.

1. Introduction

Since the 1970s there has been the efficient market hypothesis (EMH) functioning in the world of science, proposed by E. Fama. According to this hypothesis, prices of financial assets change at random, which prevents obtaining a return rate higher than the average market rate. However, one can find numerous papers that confirm the possibility of forecasting future return rates from historic values, which contradict EMH. In 2004, A. Lo proposed the adaptive market hypothesis (AMH), which coherently and logically combines the hypothesis of Fama and the possibility of achieving temporal return rates better than the market.

The adaptive market hypothesis proposed by Lo assumes the co-existence of efficiency and inefficiency. According to this hypothesis, market efficiency evolves over time, rejecting the traditional opinion that the market is either efficient or inefficient in a given time. Therefore, the efficiency of a return rate forecast for an investment may change from period to period, due to the changing conditions prevailing on the market. Based on the conducted studies, the author of AMH concluded that the growth of efficiency level on specific markets does not have to increase over time. What is more, he acknowledged that efficiency does not have to occur. Its level depends on the market players and the conditions prevailing on a given market at a specific time.

The purpose of this article is to verify if the efficiency level on the Polish stock market from October 1994 to December 2019 is changeable over time, which would coincide with the findings that result from AMH. An auxiliary task undertaken for this purpose is to verify the occurrence of linear and non-linear dependencies between the logarithmic return rates from the WIG index for a two-year rolling-window framework. To achieve this, the autocorrelation test and the BDS test were used. For the purpose presented in this manner, one may put forward the following research hypothesis of the article: the Polish stock market shows the characteristics of an adaptive market.

2. Adaptive market hypothesis − theory

In 2004, A. Lo (2004, pp. 15-29; 2005, pp. 21-44) presented his adaptive market hypothesis, which constituted a compromise between the approach of both the followers of and those sceptical about the efficient market hypothesis formulated by Fama. The adaptive market hypothesis is one of the latest models that describes the operation of financial markets. According to the author, this model does not contradict the efficient market hypothesis, but rather extends it.

The description of the financial market proposed by Lo is related to the principles of evolution: competition, reproduction, and natural selection. Proponents of this model are of the opinion that such forces affect the efficiency of markets as well as the rise or fall of profitability of financial assets, industry, business, and individual

investments. This is related to the continually changing market conditions (e.g. crises, bubbles, and depressions). Therefore, the efficiency of markets does not have to increase as postulated by EMH proponents, but may change cyclically, depending on the context and dynamics of changes that take place in their environment.

The verification of adaptability takes place similarly to the verification of the weak form of efficiency; the difference is that in the verification of the hypothesis proposed by Lo, a given time series is divided into subperiods, and next the result of statistical tests is verified for every subperiod separately. It is worth adding that the analysed subperiods overlap. That solution was used by Lo to verify the adaptability of the American capital market (Lo, 2004, p. 23), and the solution was copied by other researchers and became informally a method of adaptability verification. The same solution was adopted for the study described in this article.

The adaptive market hypothesis has gained popularity since the publication of articles by Lo, therefore the latest scientific literature comprises more papers that concern this subject. This hypothesis is usually verified on stock markets: developed and developing (Hill, Motegi, 2019, pp. 231-242; Smith, 2011, pp. 689-708), Asiatic (Noda, 2016, pp. 66-71; Todea, Ulici, and Silaghi, 2009, pp. 7-13), American (Kim, Shamsuddin, and Lim, 2011, pp. 868-879; Lim, Luo, and Kim, 2013, pp. 953-962), and African (Ndubuisi and Okere, 2018, pp. 147-156). Gradually, the adaptive market hypothesis was verified on other segments of the financial market. For example, the efficiency of the currency market (Charles, Darné, and Kim, 2012, pp. 1607--1626; Kumar, 2018, pp. 1582-1598), the bullion market (Chang, Ahmed, Ghumro, and Bhayo, 2018, pp. 52-65), and even the cryptocurrency market (Khuntia and Pattanayak, 2018, pp. 26-28) were studied. In practice, all the conducted studies confirm the changeability of an efficiency level in time, which supports AMH.

In relation to the Polish stock exchange, the described hypothesis was verified by M. Kasolik and G. Smith. The former confirmed the adaptive character of the Polish capital market (Kasolik, 2016, p. 51-64), while the latter declared the relatively high efficiency of the Polish stock market (Smith, 2011, pp. 689-708).

3. Data and methods

The WIG index was used to verify the adaptability of the Polish stock market for the described research. The index encompasses all companies listed on the Main GPW Market, which fulfil fundamental criteria of participation in indices, therefore it is often used as a benchmark for investment strategies. Data cover the period from 3 October 1994 (the day of introducing daily quotations at GPW) to 30 December 2019. The used data include daily closing rates and daily logarithmic return rates. The daily logarithmic return rates were determined with the following formula:

$$r_t = \ln\left(\frac{p_t}{p_{t-1}}\right),$$

where ln is the natural logarithm and p_t and p_{t-1} indicate daily closing price of the WIG index at time t and $t - 1$ respectively.

Figure 1 presents the analysed input time series for the WIG index, while Table 1 shows the basic descriptive statistics for this time series as well as for the time series of daily logarithmic return rates.

Fig. 1. Daily closing price of the WIG index from 03.10.1994 to 30.12.2019

Source: own elaboration.

Table 1. Descriptive statistics of the daily closing price and daily logarithmic return rates of the WIG index

Variable	Daily closing price of the WIG from 10.1994 to 03.2019	Daily logarithmic return rates of the WIG from 10.1994 to 03.2019
Number of observations	6312	6312
Average	34438	0.0002915
Standard deviation	17781	0.014144
Coefficient of variation	0.51632	48.523
Skewness	0.041446	–0.22913
Kurtosis	–1.4612	4.1187
JB test statistics value	563.306 ***	4516.72***
KPSS test statistics value	1.62622 > 0.148 (for 5% significance)	0.0807446 < 0.462 (for 5% significance)

*** Indicate significance at 1%.

Source: own elaboration.

From the significance perspective of the analysed series, the interpretation of statistics that describe daily logarithmic return rates is more important. Based on

Table 1 it can be concluded that the WIG index in the analysed period had a positive average daily logarithmic return rate. The negative value of the skewness indicates the left-sided asymmetry of the distribution. The positive value of the kurtosis indicator show the leptokurtic distribution, which means that variables in this time series are more 'focused' around an average compared to the normal distribution. The value of statistics in the Jarque-Bera test demonstrates that there is no normal distribution of the series even for a 1% level of significance. The KPSS test proves that there is no stationarity of the original series. On the other hand, the series of return rates is stationary. Daily logarithmic return rates were used to perform the autocorrelation and BDS tests.

Quenouille's autocorrelation test was used to assess the occurrence of linear dependencies. It is used for the assessment if the value of a series from a period depends on the value of a series from a previous period. For this purpose, the S statistics are used, which have an asymptotic normal distribution with parameters $N(0.1)$:

$$S = \sqrt{T}\hat{\rho}(k),$$

where: $\hat{\rho}(k)$ is k order autocorrelation and T is number of observations (Ku and Seneta 1996, pp. 621-623).

The occurrence of statistically significant relations between observations for a 5% significance level takes place when the absolute value of S statistics is higher than 1.96. In other words, the value of S statistics below the 1.96 value module means that there is no relationship of return rates (the market is efficient), while the reverse situation means the autocorrelation of return rates, which means the possibility of forecasting future return rates (the market is not efficient). Within the described test, the autocorrelation was tested using an intercept.

For the above-mentioned purpose, the significance level of autocorrelation of order from the first to the fifth was verified, and the interpretation of results for the autocorrelation of the first order was focused on. In this manner, it was verified if the value of the return rate from the preceding day has a statistically significant impact on the value of a return rate on the current day.

In order to assess the existence of a non-linear dependence, the BDS test was applied, which was developed within the chaos theory (Brock, Dechert, Scheinkman, and LeBaron, 1996, pp. 197-235). However, it is also used to study linearity and non-linearity of time series. W statistics are used to interpret results of this test, which coincide with $N(0, 1)$ distribution with the observation aiming at infinity:

$$W_{m,T}(\varepsilon) = \sqrt{T-m+1}\frac{c_{m,T}(\varepsilon) - {c_{1,T-m+1}}^{m}(\varepsilon)}{\sigma_{m,T}(\varepsilon)},$$

where $c_{m,T}(\varepsilon)$ estimates the probability that two m length vectors are within ε distance. The test results depend on the adopted values of m and ε. Based on the

suggestions of BDS test authors, in the described study the following values were applied: $\varepsilon = 1.5 \cdot \sigma$, $m = 2,3,4,5$. The final value of W statistics was obtained as an arithmetic average for all *m*s (Belaire-Franch and Contreras, 2002, p. 692).

The BDS test was used to verify the occurrence of non-linear dependences between return rates of specific financial assets. The test gives such a possibility, however only after the removal of linear dependencies from a time series. For this purpose, the procedure of bleaching a time series was used. The procedure removes linear dependencies using the model of Vector Autoregression or ordinary autoregression up to maximum $\sqrt[3]{T}$ order. The decision was taken to use the Akaike information criterion (AIC) in this procedure.

The interpretation of the BDS test was similar as in the autocorrelation test, i.e. the absolute value of W statistics below 1.96 indicates a time series that consists of independent random variables of the same distribution (the market is efficient), while the module of values above 1.96 means the occurrence of an unspecified non-linear dependence between the elements of a series (the market is not efficient).

The verification of market adaptability is similar to the verification of a weak form of efficiency, the difference being that a given time series is divided into subperiods, and next the result of statistical tests is verified for every subperiod separately. The analysed subperiods overlap.

The analysed time series was divided into 24-month subperiods, which were 'shifted' forward for a month. Hence, the two-year window with supports was used in order to provide the number of observations sufficient to generate reliable results and to carry out the analysis of how the values of specific statistics changed in time.

The first subperiod of the time series for the WIG index encompasses data from 3 October 1994 to 30 September 1996. The consecutive subperiod covers data from 2 November 1994 to 31 October 1996, i.e. when the 'shift' took place of the time series subperiod for a month. This procedure is continued until the end of the primary time series, i.e. the last subperiod covers data from 3 January 2018 to 31 December 2019. As a result, for the WIG index 280 subperiods were generated, i.e. 280 time series. For each such period, the S and W statistics were determined.

Ultimately, 1,400 autocorrelation tests were carried out in the described study (280*5 delay orders), 280 processes of removing linear dependencies, and 1,120 BDS tests (for $m = 2,3,4$ and 5).

4. Results

Figure 2 presents the values of S statistics obtained from Quenouille's autocorrelation test of the first order (a continuous line) and a critical value 1.96 for 5% significance level (a dotted line) for the WIG index. For every 24-month subperiod, one value of S statistics was determined, which was marked in the diagram for the last month of a subperiod. Periods in which a continuous line is below the dotted line are periods of inefficiency (there is a linear correlation of the first order between return rates).

On the other hand, periods in which the continuous line is situated under the dotted line are periods characterised by efficiency (no linear dependence between return rates). The same designations were applied for all the rest of the figures.

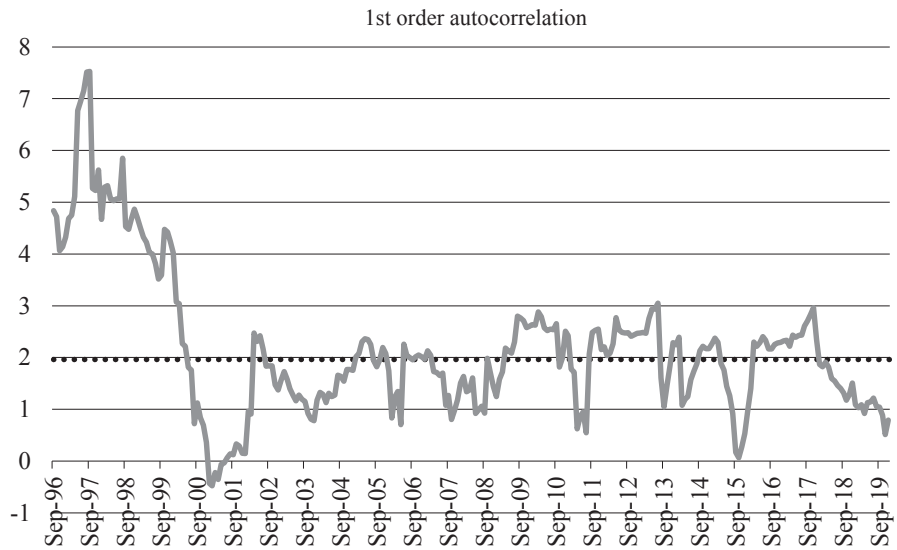

Fig. 2. Values of S statistics obtained from Quenouille's autocorrelation test of the first order

Source: own elaboration.

Considering the verification of the adaptive market hypothesis, it is worth noting the behaviour of the S statistics value over time. What is more important, such values do not fall systematically over time, which means that the efficiency of the market does not improve over time. The values in the diagram, depending on the period, are located below or above a critical value equal to 1.96 and, more importantly, such changes occur alternately, which proves Lo's hypothesis. The example of the WIG index proves that periods of efficiency and inefficiency follow each other systematically.

At an initial stage of the studied period (until October 1999), the values of S statistics were very high, which indicates the high inefficiency present among all companies listed on the Polish stock exchange. This was the initial stage of the capital market in Poland (the first quotation at the Warsaw Stock Exchange took place in April 1991) and the knowledge of the market players about its functioning might have been insufficient. On the other hand, it was a period when prices of listed assets increased substantially, without any major adjustments, not mentioning a crisis. Therefore the possibility of forecasting future return rates in that period could have been greatest and easiest. After that period the value of S statistics started to fall rapidly and has not returned to similarly high levels to this day.

Since October 1999 the value of S statistics started to fall rapidly, to the values very close to zero (December 2000-January 2002), which showed the very fast improvement of efficiency on the Polish stock market. As regards the adaptive market hypothesis, it could mean the end to the learning period and the adaptation of investors to conditions prevailing on the market.

The period of several consecutive years was characterised by the alternate occurrence of efficient and inefficient periods, however fluctuations visible in the diagram are lower, and the periods of market inefficiency are much shorter and on a lower level. This proves the relatively fast adaptation of market players to the new external conditions prevailing on the market; this situation continued until the global crisis of 2007-2009.

After that period, one could notice the higher dynamics of efficiency changes. After the crisis, the periods of inefficiency were characterised by a relative stability (they continued for quite a long time), while periods of transition to and exit from efficiency were characterised by relative suddenness (periods of efficiency lasted a relatively short time). The situation was completely different before the crisis, when the periods of inefficiency were definitely shorter than the periods of efficiency. This would mean that the periods of learning and adapting of market players continued for quite a long time, but whey then ended, the market very quickly moved to the condition of efficiency. Next, equally fast new external conditions appeared on the market, which required a new optimum solution to be found. That situation could have been influenced by the limited level of trust between entities that operated on the financial markets after the crisis. It is worth noting that in October 2015, the value of S statistics reached a value close to zero again, which proves the high level of efficiency in that period, however the market was very quickly disrupted from that point of balance.

Since November 2017 the value of S statistics has fallen systematically, and since January 2018 the market has been characterised by efficiency until the last month of the study. Since the crisis, this is the longest period of market efficiency.

As part of the conducted study, the occurrence of higher order autocorrelations was also verified (from 2 to 5), however the obtained results only supplement the results of first order autocorrelation, which is the foundation in the assessment of adaptability. The obtained results for the autocorrelation of higher orders are presented in Figure 3.

The analysis of the values obtained in Figure 3 shows that there are practically no dependencies of higher orders between the return rates of the WIG index (the continuous line of the diagram is almost always between the dotted lines). From the point of view of adaptability, however, it is more important that the values do not converge to zero over time, but get close systematically to critical values (dotted lines). This implies, despite the almost always existing efficiency of higher orders, the continuous deviation from balance levels.

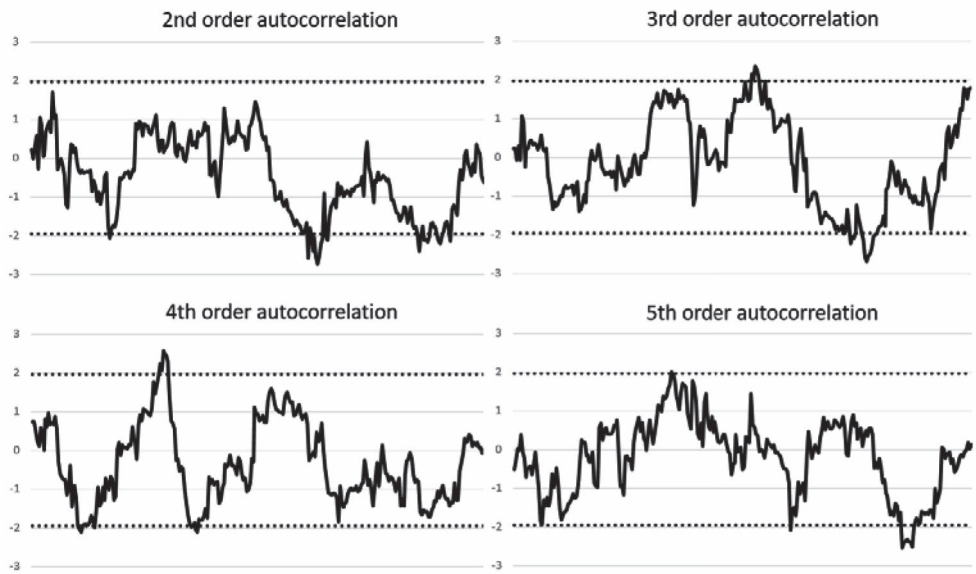

Fig. 3. Values of S statistics obtained from Quenouille's autocorrelation test of the 2nd to 5th order

Source: own elaboration.

All the considerations so far concern linear dependencies between consecutive return rates from the WIG index. However, non-linear dependencies may occur on financial markets as well. Therefore a BDS test was carried out for the same data, which detects non-linear dependencies between observations. Figure 4 presents the values of W statistics for the WIG index and a critical value for a 5% significance level.

According to the given interpretation, periods in which a continuous line is located above the dotted line are the periods of market inefficiency (the possibility of forecasting future return rates), and periods in which the continuous line is located below the dotted line are periods of market efficiency (it is not possible to forecast future return rates).

As regards the BDS test, the obtained results indicate the occurrence of two periods of inefficiency in the tested sample (from the first month of the study to March 2002 and from October 2008 to February 2016) and two periods of efficiency (from April 2002 to September 2008 and from March 2016 to the end of the study period) (except for single subperiods), which occur alternately. Nevertheless, the occurrence of such alternations is in favour of the positive verification of the hypothesis presented in the study, namely that of alternate levels of predictability of return rates over time.

It is worth focusing on the levels of efficiency and inefficiency at this point. The first period of inefficiency, as in the case of the autocorrelation test, was on a high

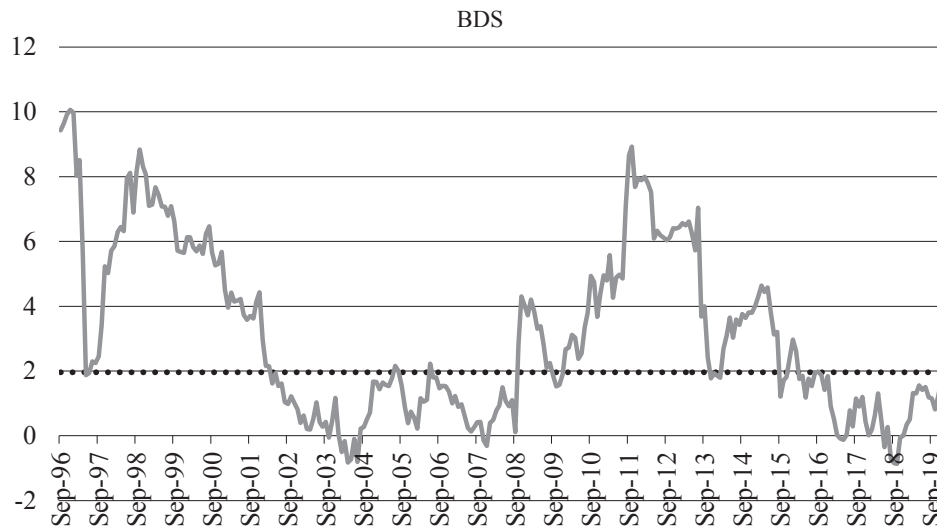

Fig. 4. Values of W statistics obtained from the BDS test

Source: own elaboration.

level; however, the second period of inefficiency that started from the global crisis was on a similar level to that from the beginning of the period, when the Polish capital market had only just developed. The results obtained, owing to the analysis of non-linear dependences, differ in this respect from the results of the autocorrelation test. On the other hand, during the efficiency periods there were months with its high level (the value of W statistics close to and lower than 1); for example, the period from December 2002 to November 2004, from January 2007 to April 2008 and from January 2017 to February 2019. It is also worth noting that according to the results of the BDS test, for the WIG index from October 2011 the level of efficiency increased (with short--term deviations) as far as January 2019, which may also prove that the market players became adapted to the market environment after the crisis of 2007-2009.

According to the analysis of Figures 2 and 4, the level of efficiency on a market depends on the situation that prevails currently in the environment. One could say that it depends on the environment in which the entities operate. This was clear, for example, during the financial crisis of 2007-2009, whose impact on the increase of inefficiency was proved with both tests.

5. Conclusions

The conducted study was aimed at analysing the level of predictability of return rates of the main Polish stock exchange index, the WIG, as a representative of the Polish stock market. In this way, the adaptive market hypothesis proposed by Lo has

been confirmed. As a measure of the possibility of forecasting future interest rates, Quenouille's autocorrelation was applied (the assessment of linear dependences) and the BDS test (the assessment of non-linear dependences).

The obtained results confirm that the predictive possibilities (the level of efficiency) change over time for the analysed index. Moreover, such changes occur cyclically (the alternate occurrence of efficiency and inefficiency periods), as suggested by Lo when he formulated his hypothesis, which is related to the adaptation of investors to changing environments. A definitely higher inefficiency for the examined index was observed in the initial period (the first years when the Polish stock exchange operated after the transformation of the economic system). It was also noted that the financial crisis of 2007-2009 affected the level of efficiency, both for linear and non-linear dependencies. Finally, evidence was found which confirms the adaptive market hypothesis for the Polish stock market.

The described research is only an introduction to further analysis of the adaptability of the Polish stock market. However, it is worth noting that the hypothesis proposed by Lo opens new possibilities for further researchers. For example, questions arise about the tempo of return to effective periods, or the possibility of forecasting an approximate transition to inefficient periods. Confirming the adaptation markets hypothesis also restores the sense of actively managing an investment portfolio.

References

Belaire-Franch, J., and Contreras, D. (2002). How to compute the BDS test: A software comparison. *Journal of Applied Econometrics*, (17).

Brock, W., Dechert, D., Scheinkman, J., and LeBaron, B. (1996). A test for independence based on the correlation dimension. *Econometric Reviews*, *15*(3).

Chang, B., Ahmed, P., Ghumro, N., Bhayo, M-U-R. (2018). Are gold markets weak form efficient? Evidence from China, India and Russia. *Sukkur IBA Journal Of Management and Business*, *5*(1).

Charles, A., Darné, O., Kim, J. (2012). Exchange-rate return predictability and the adaptive markets hypothesis: Evidence from major foreign exchange rates. *Journal of International Money and Finance*, *31*(6).

Hill, J., Motegi, K. (2019). Testing the white noise hypothesis of stock returns. *Economic Modelling*, (76).

Kasolik, M. (2016). Weryfikacja wybranych zastosowań hipotezy rynku adaptacyjnego na rynkach finansowych. *Zeszyty Naukowe Uniwersytetu Ekonomicznego w Krakowie*, *10*(958).

Khuntia, S., and Pattanayak, J. K. (2018). Adaptive market hypothesis and evolving predictability of bitcoin. *Economics Letters*, (167).

Kim, J., Shamsuddin, A., Lim, K-P. (2011). Stock return predictability and the adaptive markets hypothesis: Evidence from century-long U.S. data. *Journal of Empirical Finance*, *18*, 5.

Ku, S., and Seneta, E. (1996). Quenouille-type theorem on autocorrelations. *Annals of the Institute of Statistical Mathematics*, *48*, 4.

Kumar, D. (2018). Market efficiency in Indian exchange rates: Adaptive market hypothesis. *Theoretical Economics Letters*, 8.

Lim, K-P., Luo, W., Kim, J. (2013). Are US stock index returns predictable? Evidence from automatic autocorrelation-based test. *Applied Economics*, *45*, 8.

Lo, A. (2004). The adaptive markets hypothesis: Market efficiency from evolutionary perspective. *Journal of Portfolio Management*, *30*(5).

Lo, A. (2005). Reconciling efficient markets with behavioral finance: The adaptive markets hypothesis. *Journal of Investment Consulting*, *7*(2).

Ndubuisi, P., and Okere, K. (2018). Stock returns predictability and the adaptive market hypothesis in emerging markets: Evidence from the Nigerian capital market. *Asian Journal of Economic Modelling*, *6*(2).

Noda, A. (2016). A test of the adaptive market hypothesis using a time-varying AR model in Japan. *Finance Research Letters*, 17.

Smith, G. (2011). The changing and relative efficiency of European emerging stock markets. *The European Journal of Finance*, *18*(8).

Todea, A., Ulici, M., and Silaghi, S. (2009). Adaptive markets hypothesis: Evidence from Asia-Pacific financial markets. *The Review of Finance and Banking, 1*(1).