II

RAFAŁ CZYŻYCKI

ARITHMETIC OR LOGARITHMIC RATE OF RETURN? THE IMPACT OF THE CHOICE MADE ON THE DISTRIBUTION MODELLING RESULTS

2.1. Introduction

One of the most often raised problems in modern finances, associated with capital market, is the issue of proper modelling of rates of return from financial instruments. The simplest and the most often applied approach, which assumes normal distribution of rates of return, although highly practical, from the theoretical point of view is unacceptable. Analysing numerous rates of return, we can observe a number of their characteristics, which most often include (Pionek, 2005):

- leptokurtosis and fat tail effect in distributions of rates of return,
- return rate autocorrelation effect,
- return rates concentration effect,
- leverage effect,
- effect of long memory in volatility (variance),
- skewness effect.

The objective of this work is to examine the impact of selection of the type of the rate of return, the distribution and estimation horizon applied on the results of modelling of rates of return. For this purpose, normal and logarithmic rate of return will be used, and the following distributions will be taken into account: skewed normal, skewed t-Student, skewed GED and stable distribution. In addition, in order to specify the significance of maturity of the capital market on the quality of the models obtained, the rate of return from S&P500 and WIG will be subject to modelling.

2.2. Methodological basis

The rate of return is most often defined as the normal (arithmetic) or the logarithmic rate of return. In the case of analysis of the normal rate of return R_t, its value is established on the basis of the following formula:

$$R_t = \frac{P_t - P_{t-1} + D_t}{P_{t-1}} \tag{2.1}$$

While the logarithmic rate of return R^*_t is defined by:

$$R^*_t = \ln \frac{P_t + D_t}{P_{t-1}} \tag{2.2}$$

Where:

P_t – price of security at time *t*;
P_{t-1} – price of security in period *t-1*;
D_t – value of dividend paid in period *t*.

In literature on modelling of rates of return, both formats can be found. Among other things, a logarithmic rate of return assumes a lesser value than the ordinary rate of return, while the central theorem of Lindberg-Levy suggests that in the case of an appropriately long analysis period, the logarithmic rate of return will be described by Gauss distribution (Bednarz-Okrzyńska, 2014). Depending on the time horizon applied, we can analyse not only the daily (D), but also weekly (W), monthly (M) or annual rates of return. Subject to modelling in this article are distributions of the following rates of return:

– daily normal rate of return in the period of 252 quotations (R_t_D_252),
– daily logarithmic rate of return in the period of 252 quotations (R^*_t_D_252),
– daily normal rate of return in the period of 126 quotations (R_t_D_126),
– daily logarithmic rate of return in the period of 126 quotations (R^*_t_D_126),
– weekly normal rate of return in the period of 52 quotations (R_t_W_52),
– weekly logarithmic rate of return in the period of 52 quotations (R^*_t_W_52),
– monthly normal rate of return in the period of 36 quotations (R_t_M_36),
– monthly logarithmic rate of return in the period of 36 quotations (R^*_t_M_36),
– monthly normal rate of return in the period of 60 quotations (R_t_M_60),
– monthly logarithmic rate of return in the period of 60 quotations (R^*_t_M_60).

The above rates of return will be modelled starting from the first quotation, for which such modelling is possible (e.g. for a daily rate of return in the period of 252 quotations, the first model was obtained for the 254th quotation of a given index, the second model for the 255th quotation included rates of return from quotations 3 to 254 etc.), until the last quotation of year 2014. This means that in the case of index S&P500, for each of the distributions analysed, 11102 models were obtained for daily rates of return for the period of 252 quotations and 11228 for 126 quotations, 480 models for monthly rates of return for the period of 60 quotations and 504 for 36 quotations and 2139 models for weekly rates of return. In the case of WIG index, the number of models obtained was at the level of 4812 and 4938, 183 and 207 and 898, respectively.

Due to limitations associated with the article, the research results have been limited to four distributions: skewed normal, skewed t-Student, skewed GED and stable.

Distribution function of the skewed normal distribution (*snorm*), is described by the formula (Azzalini, 1985) :

$$f(x) = \frac{2}{\sigma}\phi\left(\frac{x-\mu}{\sigma}\right)\Phi(\lambda\cdot\frac{x-\mu}{\sigma}) \tag{2.3}$$

where: μ – location parameter,
σ-scale parameter,
λ-skewness parameter,
φ(x) – density function of standardized normal distribution,
Φ(x) – Cumulative distribution function of the standardized normal distribution.

Finally, function (2.3) can be recorded as follows:

$$f(x) = \frac{1}{\sigma\cdot\pi}\cdot e^{-0,5\cdot\left(\frac{x-\mu}{\sigma}\right)^2}\cdot\int_{-\infty}^{\lambda\cdot\left(\frac{x-\mu}{\sigma}\right)} e^{-\frac{t^2}{2}}\,dt \tag{2.4}$$

The density function of the skewed t-Student distribution has been defined as (Jones, 2003):

$$f(x) = \frac{1}{2^{a+b-1}\cdot B(a,b)\cdot(a+b)^{0,5}}\cdot\left(1+\frac{x}{(a+b+x^2)^{0,5}}\right)^{a+0,5}\cdot\left(1-\frac{x}{(a+b+x^2)^{0,5}}\right)^{b+0,5} \tag{2.5}$$

where B(·,·) –beta function, a,b>0. If a=b, function (2.5) becomes a standard t-Student function with „2*a" degrees of freedom, if a<b the function is negatively skewed, if a>b – positively skewed.

Density function of skewed GED (sGED) distribution, on the other hand, is described by the following equation (Theodossiou, 2000):

$$f(x) = \frac{C}{\sigma}\cdot\exp\left(-\frac{1}{[1-\text{sign}(x-\mu+\delta\sigma)\lambda]^k\Theta^k\sigma^k}\cdot|x-\mu+\delta\sigma|^k\right) \tag{2.6}$$

where: : $C = \frac{k}{2\Theta}\Gamma\left(\frac{1}{k}\right)^{-1}$,

$\Theta = \Gamma\left(\frac{1}{k}\right)^{0,5}\Gamma\left(\frac{3}{k}\right)^{-0,5}S(\lambda)^{-1}$,

$\delta = 2\lambda AS(\lambda)^{-1}$,

$S(\lambda) = \sqrt{1+3\lambda^2-4A^2\lambda^2}$,

$A = \Gamma\left(\frac{2}{k}\right)\Gamma\left(\frac{1}{k}\right)^{-0,5}\Gamma\left(\frac{3}{k}\right)^{-0,5}$,

k- shape parameter,

Γ- Gamma function.

In the case of stable distributions, the analytical format describing density of a random variable of such distribution can be found only in the case of three distribution classes: normal, Couch and Levy. In the remaining cases, numerical integration is normally used (Fourier transform) of the characteristic function in the following form (Czyżycki, 2014):

$$\Phi(t) = \begin{cases} \exp\left[i\mu \cdot t - \sigma|t|^{\alpha} \cdot \left(1 + i\lambda \cdot sign(t) \cdot tg \cdot \left(\frac{\alpha \cdot \pi}{2}\right)\right)\right] & dla\ \alpha \neq 1 \\ \exp\left[i\mu \cdot t - \sigma|t| \cdot \left(1 + i\lambda \cdot sign(t) \cdot \frac{\pi}{2} \cdot \ln(t)\right)\right] & dla\ \alpha = 1 \end{cases} \quad \text{(II.7)}$$

where $i = \sqrt{-1}$,

α – distribution stability parameter (for normal distribution α=2 and β=0, in the case of Couchy distribution α=2 and β=0, and for Levy distribution α=1/2 and β=1).

In the study, the following main research hypothesis has been formed: selection of normal or logarithmic rate of return does not exert significant impact on results of modelling of the rate distribution. In addition, the following auxiliary hypothesis has been applied: the difference in probability of obtaining a distribution that would be consistent with the model in the case of developed and developing capital markets is not statistically significant.

2.3. Research results

In order to verify the main hypothesis, modelling of the normal and logarithmic rate of return has been conducted for all of the distribution variants assumed earlier. Afterwards, using the Chi-square compatibility test, it was checked for how many among the *n* distributions obtained, there is no reason to reject the hypothesis of these being consistent with the theoretical distribution being analysed (*p-value*=0,05). On the basis of the above information, using the test for two structure indicators, the p-value level was determined, for which it can be assumed that the frequency (probability) of obtaining of a distribution consistent with the assumptions made differs in a statistically significant manner depending on the rate of return applied (normal or logarithmic). The research results obtained are presented in Table 2.1.

Table 2.1. Statistics of the return rate distributions modelled

Distribution	n	Number of consistent distributions		p-value for test for two structure indicators
		R_t	R^*_t	
stable_WIG_D_252	4812	4325	4331	0,8389
stable_WIG_D_126	4938	4354	4356	0,9503
stable_WIG_M_60	183	182	182	1,0000
stable_WIG_W_52	898	737	736	0,9510
stable_WIG_M_36	207	190	191	0,8560
stable_SP500_D_252	11102	9818	9811	0,8834
stable_SP500_D_126	11228	9790	9794	0,9363
stable_SP500_M_60	480	366	366	1,0000
stable_SP500_W_52	2139	1733	1722	0,6696
stable_SP500_M_36	504	362	364	0,8884
sGED_WIG_D_252	4812	4203	4208	0,8780
sGED_WIG_D_126	4938	4350	4349	0,9752
sGED_WIG_M_60	183	180	180	1,0000
sGED_WIG_W_52	898	763	760	0,8437
sGED_WIG_M_36	207	196	193	0,5359
sGED_SP500_D_252	11102	9858	9860	0,9660
sGED_SP500_D_126	11228	9898	9903	0,9177
sGED_SP500_M_60	480	397	400	0,7965
sGED_SP500_W_52	2139	1745	1753	0,7514
sGED_SP500_M_36	504	405	402	0,8131
sTS_WIG_D_252	4812	3084	3071	0,7825
sTS_WIG_D_126	4938	4006	4002	0,9181
sTS_WIG_M_60	183	182	182	1,0000
sTS_WIG_W_52	898	744	728	0,3262
sTS_WIG_M_36	207	197	197	1,0000
sTS_SP500_D_252	11102	6838	6823	0,8361
sTS_SP500_D_126	11228	8434	8428	0,9262
sTS_SP500_M_60	480	387	384	0,8076
sTS_SP500_W_52	2139	1838	1836	0,9300
sTS_SP500_M_36	504	429	426	0,7923
snorm_WIG_D_252	4812	3843	3839	0,9191
snorm_WIG_D_126	4938	2581	2575	0,9038
snorm_WIG_M_60	183	179	180	0,7027
snorm_WIG_W_52	898	736	732	0,8070
snorm_WIG_M_36	207	187	188	0,8664
snorm_SP500_D_252	11102	6802	6878	0,2943
snorm_SP500_D_126	11228	3867	3834	0,6427
snorm_SP500_M_60	480	407	410	0,7857
snorm_SP500_W_52	2139	1640	1633	0,8007
snorm_SP500_M_36	504	365	360	0,7260

Source: own work.

On the basis of the results contained in Table 2.1, it can be assumed that selection of one of the two rates of return does not have a statistically significant impact on increasing of the probability of obtaining a distribution consistent with the assumptions made. This applies not only to the rate of return in the strict sense of the term (normal or logarithmic), but also to the period, for which the rate has been determined (day, week, month), the quantity of data (256, 126, 60, 52, 36) and the degree of development of the capital market (the developed American market or the developing Polish market). Additional argument that supports the above hypothesis can be the results of the Kolmogorov Smirnov test (K_S), which was used to verify the hypothesis stating that empirical distributions of p-values obtained for the Chi-square compatibility test are identical regardless of whether a normal or a logarithmic rate of return is modelled. In each of the distributions modelled, there is no reason to reject such hypothesis (for p-value=0,05), which has been illustrated by Table 2.2.

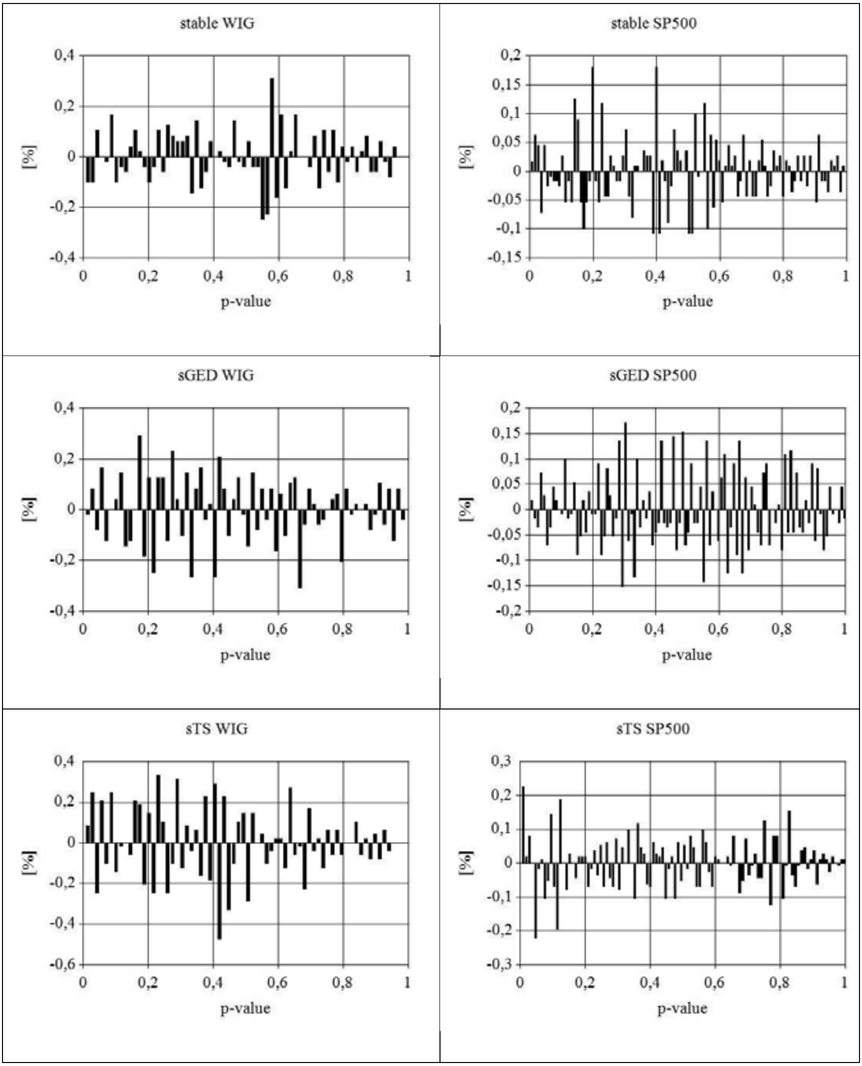
Table 2.2. Results of the Kolmogorov Smirnov test (K_S) to examine the identity of the empirical cumulative distribution function for p-values obtained for the Chi-square compatibility test in the case of modelling a given distribution on the basis of a normal or logarithmic rate of return

Distribution	K_S	p-value	Distribution	K_S	p-value
stable_WIG_D_252	0,2038	1,0000	sTS_WIG_D_252	0,4179	0,9949
stable_WIG_D_126	0,2012	1,0000	sTS_WIG_D_126	0,3220	0,9999
stable_WIG_M_60	0,6777	0,7480	sTS_WIG_M_60	0,5734	0,8974
stable_WIG_W_52	0,2594	1,0000	sTS_WIG_W_52	0,3773	0,9989
stable_WIG_M_36	0,4903	0,9698	sTS_WIG_M_36	0,5393	0,9331
stable_SP500_D_252	0,1468	1,0000	sTS_SP500_D_252	0,8187	0,5140
stable_SP500_D_126	0,2135	1,0000	sTS_SP500_D_126	0,3270	0,9999
stable_SP500_M_60	0,5947	0,8713	sTS_SP500_M_60	0,5633	0,9088
stable_SP500_W_52	0,3516	0,9997	sTS_SP500_W_52	0,3669	0,9993
stable_SP500_M_36	0,3641	0,9994	sTS_SP500_M_36	0,6518	0,7892
sGED_WIG_D_252	0,2752	1,0000	snorm_WIG_D_252	0,6421	0,8041
sGED_WIG_D_126	0,2214	1,0000	snorm_WIG_D_126	0,6339	0,8165
sGED_WIG_M_60	0,6777	0,7480	snorm_WIG_M_60	0,9383	0,3420
sGED_WIG_W_52	0,1887	1,0000	snorm_WIG_W_52	0,4717	0,9792
sGED_WIG_M_36	0,2942	1,0000	snorm_WIG_M_36	0,2942	1,0000
sGED_SP500_D_252	0,1342	1,0000	snorm_SP500_D_252	0,7784	0,5796
sGED_SP500_D_126	0,2069	1,0000	snorm_SP500_D_126	0,7807	0,5758
sGED_SP500_M_60	0,3012	1,0000	snorm_SP500_M_60	0,5343	0,9377
sGED_SP500_W_52	0,2293	1,0000	snorm_SP500_W_52	0,4433	0,9894
sGED_SP500_M_36	0,2754	1,0000	snorm_SP500_M_36	0,4541	0,9861

Source: own work.

Figure 2.1. presents, on the other hand, the differences in frequency of distributions obtained consistent with the assumptions made, in the case of modelling of normal and logarithmic daily rate of return for the estimation period consisting of 252 quotations (the positive value indicates prevalence of consistent distributions

obtained for the logarithmic rate of return, while the negative value – prevalence of distributions obtained for the normal rate).



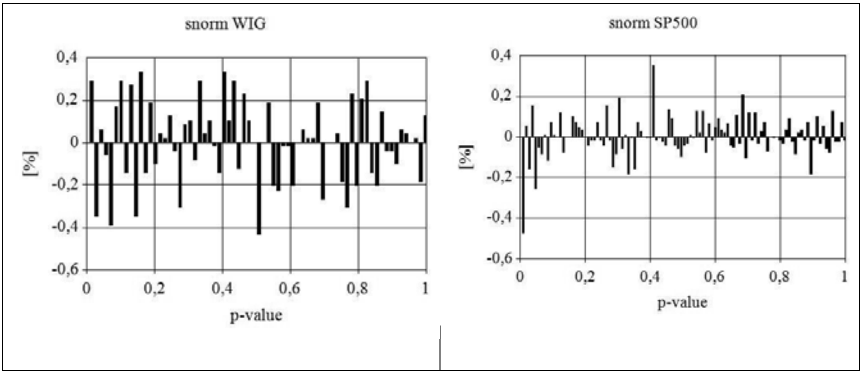


Figure 2.1. Differences in the frequency of distributions obtained being consistent with the assumptions made in the case of modelling of normal and logarithmic rate of return and the estimation period of 252 quotations.
Source: own work.

In order to verify the additional hypothesis, stating that the probability of obtaining of a distribution consistent with the assumptions made is the same for the developed and the developing capital markets, a comparison of results was conducted with regard to the modelled rates of return for SP500 and WIG indexes. Only in the case of sGED and stable distributions, modelling of normal and logarithmic rates of return on the basis of 126 quotations, as well as weekly logarithmic rates of return (and, in the case of the stable distribution, also the normal rates of return), the null hypothesis (p-value=0,05) – referring to identical probability of obtaining a distribution consistent with the assumptions made on both markets - could not be rejected. Detailed information concerning the results of the study conducted has been presented in Table 2.3.

Table 2.3. P-values for test for two structure indicators, examining the identity of frequency of occurrence of distributions consistent with the assumptions made for WIG and SP500 index rates of return

Distribution	p-value for test for two structure indicators	Distribution	p-value for test for two structure indicators
stable_R_t_D_252	0,0081	sTS_R_t_D_252	0,0028
stabile_R^*_t_D_252	0,0026	sTS_R^*_t_D_252	0,0048
stable_R_t_D_126	0,0826	sTS_R_t_D_126	2,22E-16
stabile_R^*_t_D_126	0,0807	sTS_R^*_t_D_126	4,44E-16
stable_R_t_M_60	9,77E-12	sTS_R_t_M_60	2,92E-09
stabile_R^*_t_M_60	7,86E-12	sTS_R^*_t_M_60	1,07E-09
stable_R_t_W_52	0,4971	sTS_R_t_W_52	0,0301
stabile_R^*_t_W_52	0,3516	sTS_R^*_t_W_52	0,0009
stable_R_t_M_36	3,6E-08	sTS_R_t_M_36	0,0002

stabile_R^{*}_{t}_M_36	2E-08	sTS_R^{*}_{t}_M_36	9,02E-05
sGED_R_{t}_D_252	0,0088	snorm_R_{t}_D_252	0
sGED_R^{*}_{t}_D_252	0,0135	snorm_R^{*}_{t}_D_252	0
sGED_R_{t}_D_126	0,9102	snorm_R_{t}_D_126	0
sGED_R^{*}_{t}_D_126	0,8179	snorm_R^{*}_{t}_D_126	0
sGED_R_{t}_M_60	1,01E-07	snorm_R_{t}_M_60	3,54E-06
sGED_R^{*}_{t}_M_60	1,73E-07	snorm_R^{*}_{t}_M_60	1,94E-06
sGED_R_{t}_W_52	0,0247	snorm_R_{t}_W_52	0,0013
sGED_R^{*}_{t}_W_52	0,0746	snorm_R^{*}_{t}_W_52	0,0017
sGED_R_{t}_M_36	1,94E-06	snorm_R_{t}_M_36	2,28E-07
sGED_R^{*}_{t}_M_36	9,99E-06	snorm_R^{*}_{t}_M_36	2,29E-08

Source: own work.

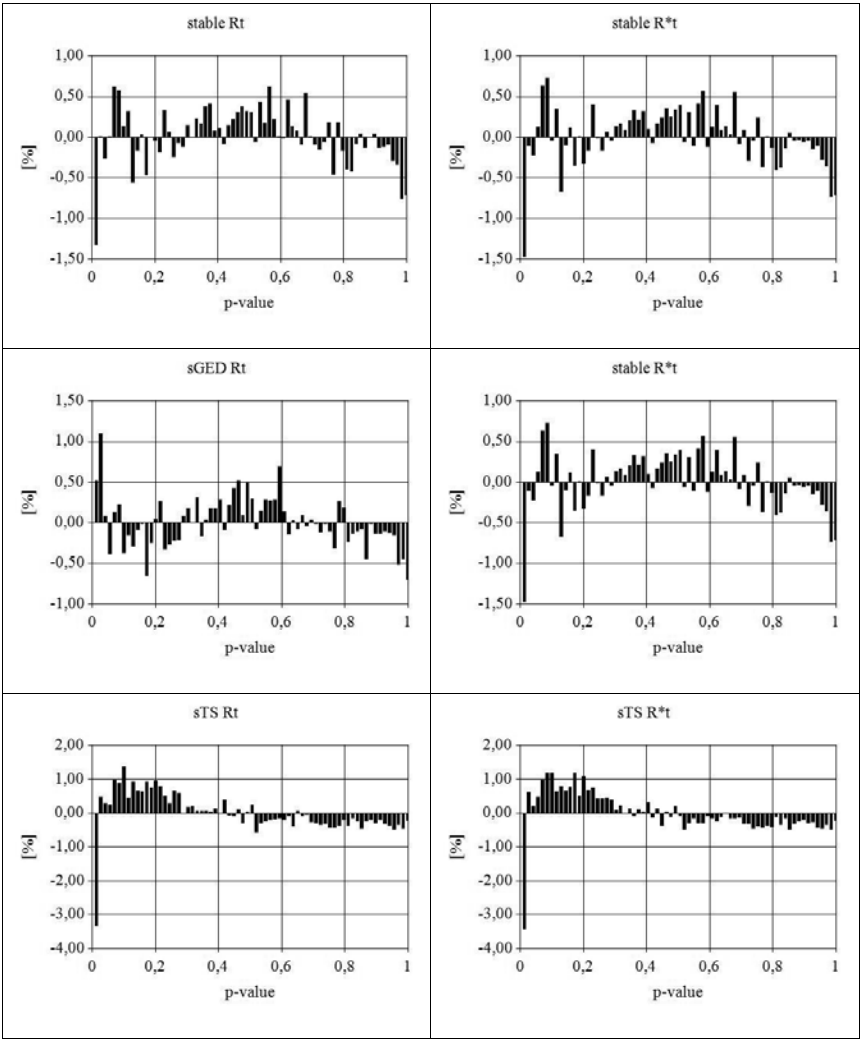
An additional argument supporting falsification of the additional hypothesis are results of the test verifying identity of p-value distributions for the Kolmogorov-Smirnov test. For each of the distribution and return rate combinations examined, the result obtained indicated clearly (p-value=0,05) that the p–value distributions for the Chi-square test examining compatibility of the model with the assumptions made differ in a statistically significant manner for SP500 and WIG indexes (Table 2.4).

Table 2.4. Results of the Kolmogorov – Smirnov test (K_S) to examine the identity of empirical cumulative distribution functions of p-values obtained for the Chi-square compatibility test, in the case of modelling of the rate of return from the SP500 and WIG indexes

Distribution	K_S	p-value	Distribution	K_S	p-value
stable_R_{t}_D_252	2,40959	1,8109E-05	sTS_R_{t}_D_252	5,90308	1,0812E-30
stabile_R^{*}_{t}_D_252	2,44784	1,2488E-05	sTS_R^{*}_{t}_D_252	6,16678	1,8592E-33
stable_R_{t}_D_126	2,60824	2,4665E-06	sTS_R_{t}_D_126	3,53851	2,6629E-11
stabile_R^{*}_{t}_D_126	2,61823	2,2220E-06	sTS_R^{*}_{t}_D_126	3,56838	1,7418E-11
stable_R_{t}_M_60	4,25596	3,6993E-16	sTS_R_{t}_M_60	4,28312	2,3263E-16
stabile_R^{*}_{t}_M_60	4,38650	3,8738E-17	sTS_R^{*}_{t}_M_60	4,71094	1,0579E-19
stable_R_{t}_W_52	1,01615	2,5309E-01	sTS_R_{t}_W_52	2,13961	2,1120E-04
stabile_R^{*}_{t}_W_52	0,90880	3,8069E-01	sTS_R^{*}_{t}_W_52	2,22076	1,0408E-04
stable_R_{t}_M_36	2,96870	4,4258E-08	sTS_R_{t}_M_36	3,00759	2,7804E-08
stabile_R^{*}_{t}_M_36	3,09437	9,6423E-09	sTS_R^{*}_{t}_M_36	3,21951	1,9855E-09
sGED_R_{t}_D_252	2,19718	1,2819E-04	snorm_R_{t}_D_252	10,84023	0,0000
sGED_R^{*}_{t}_D_252	2,34341	3,3970E-05	snorm_R^{*}_{t}_D_252	10,40061	0,0000
sGED_R_{t}_D_126	2,70091	9,2200E-07	snorm_R_{t}_D_126	10,97955	0,0000
sGED_R^{*}_{t}_D_126	2,67858	1,1725E-06	snorm_R^{*}_{t}_D_126	11,02476	0,0000
sGED_R_{t}_M_60	5,24108	2,7660E-24	snorm_R_{t}_M_60	5,78848	1,5763E-29
sGED_R^{*}_{t}_M_60	5,41991	6,1072E-26	snorm_R^{*}_{t}_M_60	6,21687	5,3774E-34
sGED_R_{t}_W_52	0,96526	3,0911E-01	snorm_R_{t}_W_52	1,82995	2,4681E-03
sGED_R^{*}_{t}_W_52	1,00169	2,6820E-01	snorm_R^{*}_{t}_W_52	1,67635	7,2471E-03
sGED_R_{t}_M_36	2,85481	1,6676E-07	snorm_R_{t}_M_36	3,35298	3,4349E-10
sGED_R^{*}_{t}_M_36	2,89574	1,0415E-07	snorm_R^{*}_{t}_M_36	3,31461	5,7298E-10

Source: own work.

The differences in empirical cumulative distribution functions p-values obtained for the Chi-square test are mainly due to a much more frequent obtaining of lower values for the SP500 index in comparison with WIG index, which has been presented by Figure 2.2.



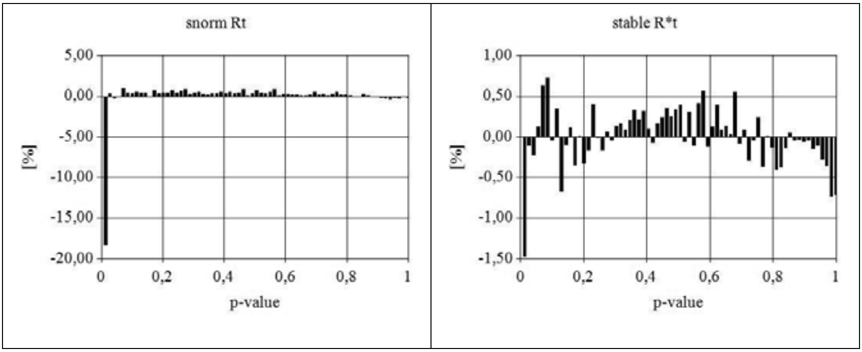


Figure 2.2. Differences in the frequency of distributions obtained, consistent with the assumptions made in the case of modelling of the rate of return for SP500 and WIG indexes and the estimation period consisting of 252 daily rates of return
Source: own work.

2.4. Conclusions

On the basis of the research conducted, it seems proper to draw the following conclusions:

- the probability of obtaining of a return rate distribution consistent with the theoretical distribution does not depend, to a statistically significant extent, on the rate of return used for modelling. Both in the case of the normal and logarithmic rates of return, the probability of obtaining a distribution consistent with the theoretical assumptions is the same, regardless of whether a daily, weekly or monthly rate is being modelled, and regardless of the length of the estimation horizon;
- of significance, on the other hand, is the level of development of the capital market. In the case of developing markets – such as the Polish capital market – the probability of obtaining of a distribution consistent with the model is significantly lower in comparison with modelling of developed stock exchange indexes (SP500).

Aneta Sokół
Irena Figurska
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MANAGEMENT – PROCESSES

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