Empirical study of relation measures of stable distributed stock returns

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Abstract. Relationships between financial instruments are very important in practical portfolio management. Under the assumption of stability, when the second moment does not exist, traditional relationship measures cannot be applied. In this paper we introduce new general correlation measures. Results of the empirical analysis of the selected equities from Baltic States market are given as an example.

Keywords: relation measures, codifference, covariation, power correlation, mixed-stable model, stable law.

1. Introduction

When constructing a financial portfolio it is essential to determine relationships between different stock returns. In classical economics and statistics (the data have finite first and second moments) the relationship between random variables (returns) is characterized by covariance or correlation. However under the assumption of stability (sets of stock returns are modelled by stable laws) covariance and correlation (Pearson correlation coefficient) can not be applied, since the variance (if the index of stability $\alpha < 2$) and the mean (if the index of stability $\alpha < 1$) do not exist. In this case we can apply rank correlation coefficients (e.g., Spearman or Kendall) or the contingency coefficient [4], [5, p. 175]. Under the assumption of stability it is purposeful to apply a generalized covariance coefficient, codifference [8] and power relation measures proposed in this paper.

The paper is organized as follows. In Section 2, we state the problem, describe the data and introduce the model. In Section 3, we define the codifference and introduce power correlation measures. Empirical results are also given in this section. In Section 4 the conclusions are given. Section 5 is devoted to the discussion of the implementation of proposed measures in the financial portfolio construction. Also it does explain the practical importance of newly proposed measures and gives some ideas on unsolved problems and further works.

2. Model and data

2.1. The problem

We focus on the analysis of relationship between the equities from the Baltic States market (Baltic I-list and Baltic Main list). Equities in these markets have some unusual properties, e.g., there may be no trades for entire weeks, see [2]. The selected 10 data

Table 1. Stable parameters of selected series (in period 2000/01/01–2007/01/25)

Equity	Full name	Country	α	β	μ	σ	p
ETLAT	Eesti Telekom	Estonia	1,5309	-0,0649	0,0004	0,0067	0,126377
GZE1R	Latvijas Gaze	Latvia	1,2656	0,0559	0,0019	0,0091	0,334848
LDJ1L	Lietuvos dujos	Lithuania	1,6094	0,1585	0,0019	0,0133	0,376351
MKO1T	Merko Ehitus	Estonia	1,6313	0,1252	0,0030	0,0118	0,339598
MNF1L	Mazeikiu nafta	Lithuania	1,6283	0,1310	0,0020	0,0162	0,329312
NRM1T	Norma	Estonia	1,6158	0,0171	0,0008	0,0071	0,188472
SNG1L	Snaige	Lithuania	1,2872	0,3317	0,0059	0,0093	0,422470
TEO1L	TEO LT	Lithuania	1,7832	0,0354	0,0000	0,0107	0,260747
VNF1R	Ventspils nafta	Latvia	1,6789	0,2737	0,0028	0,0161	0,412451
VNG1L	Vilniaus Vingis	Lithuania	1,5384	0,1209	0,0025	0,0133	0,367869

sets on the average contain 30% of observations with no price changes, i.e., 30% of daily returns are equal to zero. In [2], we have presented a univariate mixed-stable model and showed that this model fits the empirical data much better than the Gaussian or the stable. In our analysis stock prices are replaced by returns $X_i = (P_{i+1} - P_i)/P_i$, where $\{P_i\}$ is a series of stock prices. After this transform we estimate the stable parameters by the maximum likelihood method. The estimated parameters are given in Table 1. Each mixed-stable random variable is described by 5 parameters: the first one and most important is the stability index $\alpha \in (0; 2]$, which is essential when characterizing financial data. The others are: the skewness $\beta \in [-1, 1]$, the position $\mu \in \mathbf{R}$, the scale parameter $\sigma > 0$ and the index of stagnation $p = P(X = 0)$.

The results obtained show that the stability index belongs to the interval [1.26, 1.79] and thus the variance of the series does not exist, but in a further analysis we can use the first moment (mean).

2.2. The stable distribution

We say that a random variable X is distributed by the stable law [7] and denote

$$X \stackrel{d}{=} S_\alpha(\sigma, \beta, \mu),$$

where S_α is the probability density function, if a random variable has the characteristic function:

$$\phi(t) = \begin{cases} \exp\left\{ -\sigma^\alpha \cdot |t|^\alpha \cdot \left(1 - i\beta \mathrm{sgn}(t) \tan\left(\frac{\pi\alpha}{2}\right)\right) + i\mu t \right\}, & \text{if } \alpha \neq 1, \\ \exp\left\{ -\sigma \cdot |t| \cdot \left(1 + i\beta \mathrm{sgn}(t) \frac{2}{\pi} \cdot \log|t|\right) + i\mu t \right\}, & \text{if } \alpha = 1. \end{cases} \tag{1}$$

In the general case, the probability density function cannot be expressed in elementary functions. We use the Zolotarev integral expression of the probability density function in standard parameterization:

$$p(x, \alpha, \beta, \mu, \sigma)$$

$$= \begin{cases} \frac{\alpha \left| \frac{x-\mu}{\sigma} \right|^{\frac{1}{\alpha-1}}}{2\sigma \cdot |\alpha-1|} \int_{-\theta}^{1} U_\alpha(\varphi, \theta) \exp\left\{ -\left| \frac{x-\mu}{\sigma} \right|^{\frac{a}{\alpha-1}} U_\alpha(\varphi, \theta) \right\} d\varphi, & \text{if } x \neq \mu, \\ \frac{1}{\pi\sigma} \cdot \Gamma\left(1 + \frac{1}{\alpha}\right) \cdot \cos\left(\frac{1}{\alpha} \arctan\left(\beta \cdot \tan\left(\frac{\pi\alpha}{2} \right) \right) \right), & \text{if } x = \mu, \end{cases} \tag{2}$$

where $\Gamma(x)$ is gamma function,

$$U_\alpha(\varphi, \vartheta) = \left(\frac{\sin\left(\frac{\pi}{2}\alpha(\varphi + \vartheta) \right)}{\cos\left(\frac{\pi\varphi}{2} \right)} \right)^{\frac{\alpha}{1-\alpha}} \cdot \left(\frac{\cos\left(\frac{\pi}{2}((\alpha-1)\varphi + \alpha\vartheta) \right)}{\cos\left(\frac{\pi\varphi}{2} \right)} \right),$$

and

$$\theta = \arctan\left(\beta \tan \frac{\pi\alpha}{2} \right) \frac{2}{\alpha\pi} \cdot \text{sgn}(x - \mu).$$

2.3. The mixed-stable distribution

The mixed stable model was introduced by Belovas *et al.* (2006) to cope with the problem of daily zero returns. The PDF of the mixed-stable distribution is

$$f(x) = p \cdot \delta(x) + (1 - p) \cdot p_\theta(x), \tag{3}$$

where $\delta(x)$ is the Dirac delta function and $p_\theta(x)$ is the PDF of underlying stable distribution.

3. Relation measures

3.1. Codifference

Codifference of two random variables X and Y in the general case is defined through characteristic functions [9]

$$cod_{X,Y} = \ln\left(E \exp\{i(X - Y)\} \right) - \ln\left(E \exp\{iX\} \right) - \ln\left(E \exp\{-iY\} \right)$$

$$= \ln\left(\frac{E \exp\{i(X - Y)\}}{E \exp\{iX\} \cdot E \exp\{-iY\}} \right) = \ln\left(\frac{\phi_{X-Y}}{\phi_X \cdot \phi_{-Y}} \right), \tag{4}$$

or empirical characteristic functions

$$cod_{X,Y} = \ln\left(\frac{n \cdot \sum_{j=1}^{n} e^{i(X_j - Y_j)}}{\sum_{j=1}^{n} e^{iX_j} \cdot \sum_{j=1}^{n} e^{-iY_j}} \right). \tag{5}$$

here i is an complex union $i = \sqrt{-1}$.

Note that codifference calculated by this formula does not require any a priori information on the stability parameters of the compared securities. The properties of

Table 2. Norm of codifference of selected series

	TEO1L	SNG1L	VNG1L	ETLAT	GZE1R	MKO1T	NRM1T	VNF1R	LDJ1L	MNF1L
TEO1L	1,0000	−0,0195	0,0222	0,6617	0,0293	0,8279	0,0212	0,0724	0,0409	−0,0048
SNG1L	−0,0195	1,0000	0,0492	−0,0018	0,0315	0,0025	−0,0038	−0,0172	0,0032	0,0071
VNG1L	0,0222	0,0492	1,0000	0,0118	0,1386	0,0395	0,0313	0,1376	0,0196	0,0959
ETLAT	0,6617	−0,0018	0,0118	1,0000	0,0183	0,6755	0,0141	0,0398	0,0057	0,0092
GZE1R	0,0293	0,0315	0,1386	0,0183	1,0000	0,0474	0,0355	0,0910	0,0092	0,0495
MKO1T	0,8279	0,0025	0,0395	0,6755	0,0474	1,0000	0,0357	0,0293	0,0173	0,0218
NRM1T	0,0212	−0,0038	0,0313	0,0141	0,0355	0,0357	1,0000	0,0778	0,0330	0,0502
VNF1R	0,0724	−0,0172	0,1376	0,0398	0,0910	0,0293	0,0778	1,0000	−0,0055	0,0376
LDJ1L	0,0409	0,0032	0,0196	0,0057	0,0092	0,0173	0,0330	−0,0055	1,0000	0,0430
MNF1L	−0,0048	0,0071	0,0959	0,0092	0,0495	0,0218	0,0502	0,0376	0,0430	1,0000

codifference are analyzed in detail by Samorodnitsky and Taqqu (2000), and Rosadi and Deisler (2004). In the general case, the following inequalities

$$\left(1 - 2^{\alpha-1}\right) \ln\left(\frac{1}{E \exp\{iX\} \cdot E \exp\{-iY\}}\right) \leqslant cod_{X,Y}$$

$$= \ln\left(\frac{E \exp\{i(X-Y)\}}{E \exp\{iX\} \cdot E \exp\{-iY\}}\right) \leqslant \ln\left(\frac{1}{E \exp\{iX\} \cdot E \exp\{-iY\}}\right),$$

are valid and, if we divide both sides by $-\ln(E \exp\{iX\} \cdot E \exp\{-iY\})$, we will get the following system of inequalities for the generalized correlation coefficient

$$\left(1 - 2^{\alpha-1}\right) \leqslant corr_{X,Y} = -\frac{\ln\left(\frac{E \exp\{iX\} \cdot E \exp\{-iY\}}{E \exp\{i(X-Y)\}}\right)}{\ln(E \exp\{iX\} \cdot E \exp\{-iY\})} \leqslant 1. \tag{6}$$

If $0 < \alpha \leqslant 1$, this correlation coefficient is only non-negative, and if $\alpha = 2$, $\beta = 0$, then $-1 \leqslant corr_{X,Y} = \rho_{X,Y} \leqslant 1$ is the equivalent to the Pearson correlation coefficient.

Codifference is calculated for ten equities with the longest series (MNF1L, LDJ1L, VNF1R, NRM1T, MKO1T, GZE1R, ETLAT, VNG1L, SNG1L, and TEO1L). The correlation tables are presented for the series of equalized length 1427.

One can see (Table 2) that there is strong linear relation between TEO, ETL and MKO, as well as some between GZE and VNF. TEO and ETL are Lithuanian and Estonian telecommunication companies, respectively, so the relationship is obvious. The strongest relation between MKO and TEO is of interest because it is from different industries and different countries. A weak dependence between GZE and VNF is mostly influenced by the imported energy resources from Russia (gas and oil, respectively).

However, in practical implementations, especially in the portfolio theory (see Section 5), covariance (or equivalent measure) is more useful, since in that case we do not need to know the variance. The generalized covariance (Table 3) is calculated for the previously mentioned series.

Table 3. Codifference of selected series

	TEO1L	SNG1L	VNG1L	ETLAT	GZE1R	MKO1T	NRM1T	VNF1R	LDJ1L	MNF1L
TEO1L	7,37E-04	−1,13E-05	1,26E-05	5,98E-04	2,01E-05	6,03E-04	1,14E-05	3,53E-05	2,57E-05	−2,76E-06
SNG1L	−1,13E-05	4,21E-04	2,03E-05	−1,37E-06	1,66E-05	1,41E-06	−1,44E-06	−5,67E-06	1,52E-06	2,93E-06
VNG1L	1,26E-05	2,03E-05	4,04E-04	8,73E-06	7,20E-05	2,22E-05	1,16E-05	4,41E-05	9,08E-06	3,87E-05
ETLAT	5,98E-04	−1,37E-06	8,73E-06	1,07E-03	1,56E-05	6,05E-04	9,95E-06	2,60E-05	4,57E-06	6,77E-06
GZE1R	2,01E-05	1,66E-05	7,20E-05	1,56E-05	6,35E-04	3,21E-05	1,73E-05	3,97E-05	5,31E-06	2,57E-05
MKO1T	6,03E-04	1,41E-06	2,22E-05	6,05E-04	3,21E-05	7,19E-04	1,89E-05	1,40E-05	1,07E-05	1,22E-05
NRM1T	1,14E-05	−1,44E-06	1,16E-05	9,95E-06	1,73E-05	1,89E-05	3,38E-04	2,24E-05	1,42E-05	1,86E-05
VNF1R	3,53E-05	−5,67E-06	4,41E-05	2,60E-05	3,97E-05	1,40E-05	2,24E-05	2,37E-04	−2,10E-06	1,20E-05
LDJ1L	2,57E-05	1,52E-06	9,08E-06	4,57E-06	5,31E-06	1,07E-05	1,42E-05	−2,10E-06	5,22E-04	1,99E-05
MNF1L	−2,76E-06	2,93E-06	3,87E-05	6,77E-06	2,57E-05	1,22E-05	1,86E-05	1,20E-05	1,99E-05	4,03E-04

3.2. *Power correlation measures*

We propose the following relation measure

$$\rho(X, Y) = 1 - \frac{\sum_{i=1}^{N} \left| \frac{X_i - \hat{\mu}_X}{\hat{s}_X} - \frac{Y_i - \hat{\mu}_Y}{\hat{s}_Y} \right|^{\gamma}}{\sum_{i=1}^{N} \left| \frac{X_i - \hat{\mu}_X}{\hat{s}_X} \right|^{\gamma} + \left| \frac{Y_i - \hat{\mu}_Y}{\hat{s}_Y} \right|^{\gamma}} \tag{7}$$

with three standardizations depending on $\gamma = \min(\alpha_X, \alpha_Y)$ an existing moment, here α_X and α_Y are estimates of stability parameters of random variables X and Y respectively (on the estimation problems see [1]).

Depending on γ we propose to use three standardizations: the universal one (for general case), and two special standardizations: absolute deviation standardization (for $1 < \gamma < 2$, when the mean exists) and median standardization (for $\gamma < 1$).

Universal standardization. In the general case, $\hat{\mu}_{\bullet}$ is the estimate of the location parameter, $\hat{s}_{\bullet} = \hat{\sigma}_{\bullet}$ is the estimate of the scale parameter. This method could be applied with every possible stability index.

Note that if $\gamma = 2$, then $\hat{\mu}_{\bullet}$ and $\hat{s}_{\bullet}$ can be replaced by the mean and the standard deviation respectively.

Absolute deviation standardization. In the case when $\gamma \in (1; 2)$, we can apply absolute deviation standardization

$$\hat{s}_X = \frac{1}{n} \sum_{i=1}^{n} \left| X_i - \bar{\mu}_X \right| \quad \text{and} \quad \hat{s}_Y = \frac{1}{n} \sum_{i=1}^{n} \left| Y_i - \bar{\mu}_Y \right|, \tag{8}$$

here $\bar{\mu}_{\bullet}$ is the mean of underlying series.

Median standardization. In the case where $\gamma < 1$ (as well as in the general case), $\hat{\mu}_{\bullet}$ can be replaced by the median $m_{\bullet}$ and the $\hat{s}_{\bullet}$ by the following normalization constant:

$$\hat{s}_X = median \left| X - m_X \right| \quad \text{and} \quad \hat{s}_Y = median \left| Y - m_Y \right|. \tag{9}$$

The norm of codifference and power correlation measures indicates the strength and direction of a linear relationship between two random variables. Depending on the moment γ, these relation measures are bounded [8]:

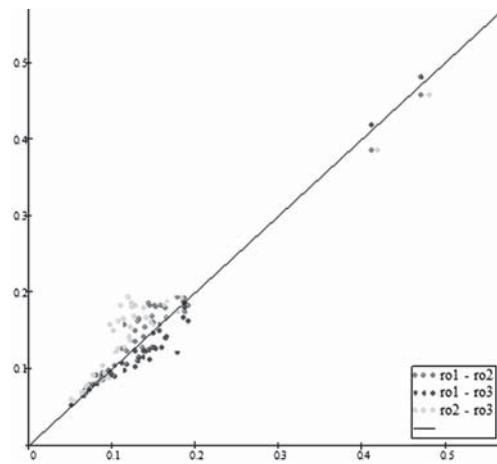$$1 - 2^{\gamma-1} \leqslant \rho(X, Y) \leqslant 1.$$

Fig. 1. Empirical scatter plot of three relation measures proposed (Tables 4–6).

Table 4. Power correlation of selected series with universal standardization

	TEO1L	SNG1L	VNG1L	ETLAT	GZE1R	MKO1T	NRM1T	VNF1R	LDJ1L	MNF1L
TEO1L	1,0000	0,1651	0,0871	0,3852	0,0852	0,5668	0,1499	0,1738	0,0878	0,0679
SNG1L	0,1651	1,0000	0,1665	0,1550	0,1798	0,1687	0,1269	0,1814	0,1826	0,1423
VNG1L	0,0871	0,1665	1,0000	0,0753	0,1923	0,0881	0,1823	0,1875	0,0915	0,1607
ETLAT	0,3852	0,1550	0,0753	1,0000	0,0721	0,4575	0,1584	0,1036	0,0588	0,0917
GZE1R	0,0852	0,1798	0,1923	0,0721	1,0000	0,0829	0,1826	0,1577	0,0783	0,1365
MKO1T	0,5668	0,1687	0,0881	0,4575	0,0829	1,0000	0,1623	0,0935	0,0571	0,0934
NRM1T	0,1499	0,1269	0,1823	0,1584	0,1826	0,1623	1,0000	0,1934	0,1827	0,1861
VNF1R	0,1738	0,1814	0,1875	0,1036	0,1577	0,0935	0,1934	1,0000	0,0686	0,1224
LDJ1L	0,0878	0,1826	0,0915	0,0588	0,0783	0,0571	0,1827	0,0686	1,0000	0,1264
MNF1L	0,0679	0,1423	0,1607	0,0917	0,1365	0,0934	0,1861	0,1224	0,1264	1,0000

In the general statistical usage, they refer to the departure of two variables from independence, however, if $\rho(X, Y) = 0$, we cannot say that random variables X and Y are independent.

The maximal and average range (see Fig. 1 and Tables 4–6) of the three above measures, respectively, is equal to 0.0724 and 0.016.

4. Conclusions

In this paper, a new power correlation measure with three standardizations is proposed. The relationship of 10 Baltic market equities was studied using the codifference and the proposed measure. Three different standardizations are discussed and empirical results are given. The analysis of the tables shows that any of these measures may be used to describe the relationship (depending on the power parameter γ). However,

Table 5. Power correlation of selected series with absolute deviation standardization

	TEO1L	SNG1L	VNG1L	ETLAT	GZE1R	MKO1T	NRM1T	VNF1R	LDJ1L	MNF1L
TEO1L	1,0000	0,1328	0,0899	0,4118	0,0888	0,5701	0,1289	0,1882	0,0974	0,0687
SNG1L	0,1328	1,0000	0,1663	0,1404	0,1645	0,1486	0,1373	0,1530	0,1926	0,1390
VNG1L	0,0899	0,1663	1,0000	0,0690	0,1883	0,0902	0,1511	0,1855	0,0825	0,1498
ETLAT	0,4118	0,1404	0,0690	1,0000	0,0685	0,4716	0,1156	0,1038	0,0523	0,0789
GZE1R	0,0888	0,1645	0,1883	0,0685	1,0000	0,0859	0,1598	0,1572	0,0734	0,1283
MKO1T	0,5701	0,1486	0,0902	0,4716	0,0859	1,0000	0,1326	0,0992	0,0575	0,0906
NRM1T	0,1289	0,1373	0,1511	0,1156	0,1598	0,1326	1,0000	0,1784	0,1455	0,1450
VNF1R	0,1882	0,1530	0,1855	0,1038	0,1572	0,0992	0,1784	1,0000	0,0673	0,1185
LDJ1L	0,0974	0,1926	0,0825	0,0523	0,0734	0,0575	0,1455	0,0673	1,0000	0,1122
MNF1L	0,0687	0,1390	0,1498	0,0789	0,1283	0,0906	0,1450	0,1185	0,1122	1,0000

Table 6. Power correlation of selected series, calculated by median standardization

	TEO1L	SNG1L	VNG1L	ETLAT	GZE1R	MKO1T	NRM1T	VNF1R	LDJ1L	MNF1L
TEO1L	1,0000	0,1145	0,0889	0,4185	0,0881	0,5678	0,1031	0,1800	0,0971	0,0677
SNG1L	0,1145	1,0000	0,1417	0,1225	0,1391	0,1266	0,1157	0,1253	0,1631	0,1219
VNG1L	0,0889	0,1417	1,0000	0,0693	0,1853	0,0916	0,1276	0,1672	0,0799	0,1468
ETLAT	0,4185	0,1225	0,0693	1,0000	0,0677	0,4811	0,0980	0,0889	0,0520	0,0783
GZE1R	0,0881	0,1391	0,1853	0,0677	1,0000	0,0858	0,1287	0,1504	0,0723	0,1230
MKO1T	0,5678	0,1266	0,0916	0,4811	0,0858	1,0000	0,1093	0,0919	0,0573	0,0907
NRM1T	0,1031	0,1157	0,1276	0,0980	0,1287	0,1093	1,0000	0,1210	0,1117	0,1233
VNF1R	0,1800	0,1253	0,1672	0,0889	0,1504	0,0919	0,1210	1,0000	0,0633	0,1052
LDJ1L	0,0971	0,1631	0,0799	0,0520	0,0723	0,0573	0,1117	0,0633	1,0000	0,1080
MNF1L	0,0677	0,1219	0,1468	0,0783	0,1230	0,0907	0,1233	0,1052	0,1080	1,0000

the estimation of the effectiveness of these measures, as well as in-depth analytical research, should be the course of further works.

It must be noted that the meaning of power correlation measures could be better explained and understood than the codifference, here we do not need complex numbers, which usually confuse practitioners and economists. Of course they might be used not only for stable random variables.

5. Discussion

The investment portfolio structure can be described by the relation measures between the shares (see Tables 2–6) and as the investment effectiveness ratios of the portfolio components. The mentioned effectiveness (in classical economics) is usually measured by the Shape ratio, but if we have the investment portfolio with stable returns, this ratio cannot be calculated, because $S = (\bar{R} - r_m)/\sigma$ depends on standard deviation, where r_m is a return of market or benchmark assets. In such cases, other ratios are used (see [3, 6,9]), but we suggest using the same Shape ratio, replacing the standard deviation by

the estimate of the scale parameter σ, and the expected return $\bar{R}$ of portfolio by the median of portfolio (if $\alpha \leqslant 1$).

In the case of a multishare portfolio ($n > 2$), together with weight optimization, a diversification problem must be solved. When $n > 2$, some weights might shrink to zero and such an investment loses the sense.

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REZIUMĖ

I. Belovas, A. Kabašinskas, L. Sakalauskas. Stabiliai pasiskirsčiusių akcijų grąžų saryšio matų empirinis tyrimas

Darbe siūlomi ryšio tarp atskirų akcijų grąžų nustatymo metodai leidžia ryšį tarp sekų nustatyti netgi tuo atveju, kai neegzistuoja atsitiktinių dydžių dispersija ar vidirkis. Tam galima naudoti kovariantiškumo (simetriniams atsitiktiniams dydžiams) bei kodiferencijos matus, kurių reikšmingumą galima nustatyti savirankos metodu. Kita vertus darbe siūlomi nauji apibendrinti ryšio stiprumo matai. Kaip pavyzdys pateikiami Baltijos šalių rinkos išrinktųjų vertybinių popierių empirinės analizės rezultatai.

Raktiniai žodžiai: ryšio matai, kodiferencija, kovariacija, laipsninė koreliacija, mišrusis-stabilusis modelis, stabilusis skirstinys.