Krzysztof Echaust

Uniwersytet Ekonomiczny w Poznaniu
Wydział Informatyki i Gospodarki Elektronicznej
Katedra Badań Operacyjnych
k.echaust@ue.poznan.pl

Małgorzata Just

Uniwersytet Przyrodniczy w Poznaniu
Wydział Ekonomiczno-Społeczny
Katedra Finansów i Rachunkowości
m.just@up.poznan.pl

GEOMETRY OF CRISES ON THE MARKET OF STOCKS LISTED ON THE WARSAW STOCK EXCHANGE

Summary: This paper defines and interprets the changes in the stock market space. There are analyzed 73 companies listed on the Warsaw Stock Exchange in the period from beginning 2006 to the end of September 2012. This is a period, covering entirely the last two financial crises from their first symptoms to the moment when these researches have been carried out. The dynamics of the stock market space was investigated using an index, which measures the evolution of the distortion effect in the shape of the market space. This index is based on geometry technique and it proved to be useful in the Polish capital market. It allows for proper identification and interpretation of the most turbulent periods in financial markets.

Keywords: financial market, crisis analysis, geometry method, market space.

Introduction

There are multiple papers dedicated to research on discovery of behavior patterns for a relationship among financial instruments [Araújo, Louçă, 2004, 2007, 2008a, 2008b; Mantegna 1999; Onnela, Chakraborti, Kaski, Kertész, 2002, 2003; Rak, 2008; Sandoval Junior, de Paula Franca, 2011]. Determination of this relationship is important for understanding the behavior of such a complex system as financial markets, but also from the practical viewpoint in the choice of an investment strategy and risk management.

The measure which is most commonly used for studying relationships between financial instruments is Pearson's linear correlation coefficient. Using that coefficient, J.C. Gower [1966] defined a metric which was later used by R.N. Mantegna [1999; Mantegna, Stanley, 2000] to define the distance between returns from securities. The fact that a metric was introduced between securities gave the meaning of geometrical concepts to securities and allowed for using geometry tools to define the structure of a securities market. This structure is understood as a system of interrelations between the prices of these instruments. Using geometry tools, one may analyze distances between market elements through common (hidden) market space dimensions. These dimensions are not directly observable and their interpretation cannot often be clearly specified. However, one may study distortion of the market space defined by these dimensions emerging as a consequence of various occurrences on financial markets, such as booms, falls, or crashes. A method of stock market space reconstruction has been presented by i. a., R.V.Mendes, T. Araújo, and F. Louçă [2003]. They studied the structures of markets built of stocks in DJIA and S&P indices.

The structure of relations between securities varies, particularly under the influence of group behaviors during periods of crises [Araújo, Louçă, 2004]. Typically, correlation structure will strengthen during these periods [Araújo, Louçă, 2004, 2007, 2008a, 2008b; Onnela, Chakraborti, Kaski, Kertész, 2003; Sandoval Junior, de Paula Franca, 2011]. Depending on the type of market perturbations, changes in its structure may vary in shape. To capture these variations, T. Araújo and F. Louçă [2007] have defined an index of securities market space shape evolution. It provides grounds for identification and interpretation of market distortion periods and analysis of their intensity and dynamics. For this reason, it may also be referred to as the risk index. This index also contributes to identification of these market sectors which are related to significant changes along the main dimensions (directions) of the changing market space.

The purpose of this paper is to study the dynamics of subprime credit crisis and the European debt crisis on the market of stocks listed at the Warsaw Stock Exchange, through identifying and interpreting changes in this market space. Specifically, the impact of various phases of these crises on the market space of stocks of specific sector companies will be analyzed.

The paper consists of two parts. The first part of the paper presents details of the method of measuring stock market space distortion dynamics. The second part will include a description and interpretation of research concerning market space distortion dynamics for stocks listed at WSE and for sector-oriented market spaces of shares during the period from the beginning of January 2006 to the end of September 2012. Key results of research work will be summarized at the end of this paper.

1. Method[1]

An index that quantifies the dynamics of stock market space distortion can be presented in six consecutive stages [see Araújo, Louçă, 2007, 2008b]:

1) a representative group N of stocks (for the market, sector) is selected, and historical returns over a certain time interval are determined;
2) a matrix of distance $\mathbf{D}$ between N stocks is computed;
3) based on the distance matrix, coordinates N of shares are determined in Euclidean space with dimension $m \le N-1$; for reduction of stock-defining coordinates, normalized eigenvectors should be determined with corresponding eigenvalues of scalar products matrix $\mathbf{B}$;
4) the computations given in sections 2 and 3 are repeated for randomly generated returns, with the same mean and variance as historical returns;
5) the eigenvalues obtained in sections 3 and 4 are compared, and d highest eigenvalues are selected so that the difference between the eigenvalues obtained for historical and random returns does not vary "significantly"; thus determined value d defines the effective dimensioning of the stock market;
6) index S is computed as the sum of quotients of differences between the d highest eigenvalues determined in 4 and 3 and the eigenvalues computed in 4; index S measures stock market space distortion.

In the first stage, return from i-th share during the time period t is computed as the difference of logarithms of stock prices $S_{i,t}$ and $S_{i,t-1}$ during the periods t and $t-1$, namely

$$r_{i,t} = \ln S_{i,t} - \ln S_{i,t-1},\ i = 1,...,N,\ t = 1,...,n. \tag{1}$$

In this way, N time series of returns are obtained $\{\mathbf{r}_i\} \in R^n$, $\mathbf{r}_i = (r_{i1}, r_{i2}, ..., r_{in})^T$, $i = 1,..., N.$

In the second stage, coordinates of the matrix of distance between N stocks (rates of return) are computed. Distance is defined as Euclidean metric between standardized return vectors, namely:

$$\mathbf{D} = [d_{ij}],\ d_{ij} = \sqrt{2(1-\rho_{ij})} = \left\| \mathbf{z}_i - \mathbf{z}_j \right\|,\ i, j = 1,..., N, \tag{2}$$

where:

$\mathbf{z}_i = (z_{i1}, z_{i2}, ..., z_{it}, ..., z_{in})^T$,

[1] This method is described in the Polish language in the work [Just, 2013].

$z_{it} = (r_{it} - \bar{r}_i)/s_i$,

$\bar{r}_i$, s_i – mean and standard deviation of the returns of *i*-th stock,

ρ_{ij} – Pearson's linear correlation coefficient between the return of *i*-th and *j*-th stock.

In the third stage, using the classic multidimensional scaling method, coordinates of N stocks are computed on the basis of distance matrix in Euclidean space with dimension $m \le N-1$. In this way, a set of N stocks is represented by a set of N points in m-dimensional space, namely $\{\mathbf{x}_i\} \in R^m$, $\mathbf{x}_i = (x_{i1}, x_{i2}, ..., x_{im})^T$, $i = 1,..., N$, $m \le N-1$.

The classic multidimensional scaling algorithm can be presented as follows [see Walesiak, Gatnar (red.), 2009]. If one determines the configuration of points $\mathbf{x}_i, i = 1,..., N,$ in a m-dimensional Euclidean space and it is assumed that the center of mass for the configuration of these points is at the origin of coordinates, i.e. $\sum_{i=1}^{N} x_{ia} = 0,\ \ a = 1,..., m,$, then squared Euclidean distance between points $\mathbf{x}_i$ and $\mathbf{x}_j$ can be noted as follows:

$$d_{ij}^2 = (\mathbf{x}_i - \mathbf{x}_j)^T (\mathbf{x}_i - \mathbf{x}_j) = \mathbf{x}_i^T \mathbf{x}_i + \mathbf{x}_j^T \mathbf{x}_j - 2\mathbf{x}_i^T \mathbf{x}_j,\ \ i, j = 1,..., N. \qquad (3)$$

On the basis of formula (3), scalar products matrix is defined

$$\mathbf{B} = \mathbf{X}\mathbf{X}^T,\ \ \mathbf{X} = (\mathbf{x}_1, \mathbf{x}_2, ..., \mathbf{x}_N)^T. \qquad (4)$$

Matrix $\mathbf{B}$ is a symmetrical matrix with rank equal to m and can be presented as

$$\mathbf{B} = \mathbf{V}\Lambda\mathbf{V}^T, \qquad (5)$$

where:

$\mathbf{\Lambda} = \text{diag}(\lambda_1, \lambda_2, ..., \lambda_m)$, $\lambda_1 \ge \lambda_2 \ge ... \ge \lambda_m > 0$ is a diagonal matrix of positive eigenvalues and $\mathbf{V} = (\mathbf{v}_1, \mathbf{v}_2, ..., \mathbf{v}_m)$ is a matrix of normalized eigenvectors.

From formulas (4) and (5), coordinates can be determined of points

$$\mathbf{X} = \mathbf{V}\mathbf{\Lambda}^{1/2}, \qquad (6)$$

where:

$\mathbf{\Lambda}^{1/2} = \text{diag}(\lambda_1^{1/2}, \lambda_2^{1/2}, ..., \lambda_m^{1/2})$.

To reduce the stock-defining coordinates, one should continue to the fifth stage.

In the next fourth stage, random returns are generated, with the same mean and variance as the historical returns, for a set of N stocks. These are derived from permutation of historical returns. For the series of returns of specific stocks thus determined, there is no correlation between the series.

In the fifth stage, on the basis of a factor scree plot, d eigenvalues are selected so that for consecutive eigenvalues obtained for historical returns, the factor scree plot has mild decline. For other eigenvalues, factor scree plots for historical and random returns are almost parallel because the factor scree plot for random returns has mild decline for all eigenvalues. The computed value d defines the effective stock market space dimension while the market space is reduced to d -dimensional subspace which corresponds to correlation structure between the shares. Eigenvectors associated with the d highest eigenvalues set the main directions of the market subspace. Research results [Araújo, Louçă, 2004, 2007, 20008a] indicate that in "normal" market functioning periods, eigenvalues computed for actual returns do not vary greatly from eigenvalues for random returns. However, in the disturbed periods, differences can be observed on the market in factor scree plot declines for historical and random returns. Market space shrinks along effective dimensions during these periods, while in periods of "normal" functioning it will behave in a similar way as for random occurrences.

In the final stage, index S is computed as the sum of quotients of differences between the d highest eigenvalues determined in sections 4 and 3 and the eigenvalues determined in 4. It has the following form:

$$S = \sum_{i=1}^{d} \left((\lambda_i' - \lambda_i) / \lambda_i' \right) = \sum_{i=1}^{d} \left(1 - \lambda_i / \lambda_i' \right), \tag{7}$$

where:

λ_i is the i -th eigenvalue for historical returns,

λ_i' – i -th eigenvalue for random returns.

This index measures the effect of stock market space distortion and can be referred to as the risk index.

2. Empirical studies

2.1. Description of data

Research has covered multiple returns from stocks in sector-oriented indexes: WIG banks, WIG construction, WIG chemicals, WIG developers, WIG energy, WIG IT, WIG media, WIG FMCG, WIG raw materials, WIG telecommunication, WIG fuels, as at September 28, 2012. Companies in the following segments were considered: banks, construction, developers, IT and FMCG, as well as from three sectors: finance, industry, utilities. Analysis of the remaining segments was not possible due to insufficient number of companies constituting these segments. The banks segment comprised 10 companies, construction – 14, developers – 9, IT – 9, FMCG – 11. The first sector was composed of 19 companies in "banks" and "developers" segments; the second sector was composed of 34 companies in "construction", "chemicals", "FMCG", "raw materials", "fuels"; the third sector comprised 20 companies in the following segments: "energy", "IT", "media", "telecommunication". The study covered the period from the beginning of January 2006 to the end of September 2012. This choice of period was determined by the intention to take account of the period of first symptoms of subprime credit crunch, while the end date is the time this research was conducted. The research only covers those companies which were listed throughout that period – 73 companies in aggregate. Daily logarithmic returns were analyzed, computed on the basis of closing price, adjusted by splits, dividend, mergers and cuts of subscription rights. 1694 returns were considered throughout that period.

2.2. Effective dimension of stock market space

In this point, effective dimension of stock market space was determined. The minimum number of hidden dimensions of stock market space, which illustrate the correlation between the stocks, was computed. For this purpose, fig. 1 presents the twenty largest eigenvalues obtained for historical and random daily logarithmic returns for all the companies throughout the period of analysis.

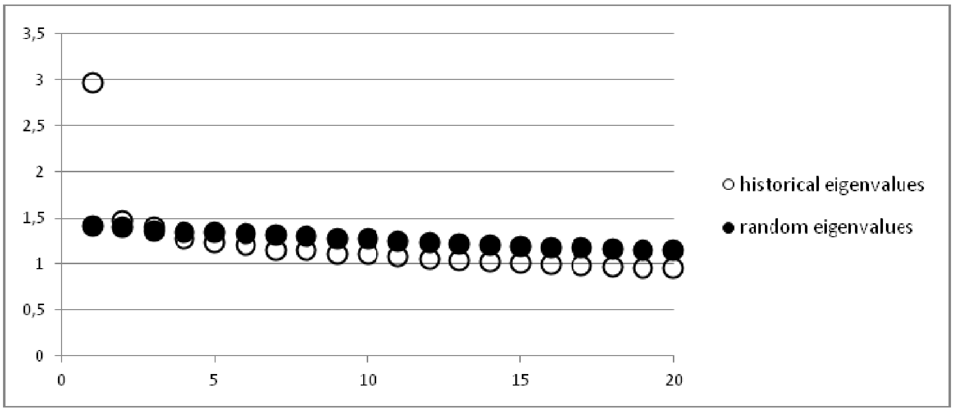

Fig. 1. Eigenvalues for historical and random returns for all companies during 2.01.2006-28.09.2012

Based on factor scree plot for historical returns, six highest eigenvalues were chosen; for the remaining eigenvalues, factor scree plots for historical and random returns are almost parallel. The defined number of eigenvalues determines the effective dimension of stock market space. This limits the stock market space to 6-dimensional subspace, which mirrors the correlation structure.

One might speculate that the effective dimension of market space depends on the companies forming the market and on the period in which that market is studied [Araújo, Louçă, 2004]. To verify this speculation, stock market space dimension was studied for different industry sectors and for the whole stock market, dividing the studied period into six semiannual sub-periods and one nine-month sub-period. Effective dimensions of sectoral market spaces turned out to be smaller than for the entire stock market. In further research, it has been decided to assume the effective dimension of the whole stock market space.

2.3. Dynamics of crises on the stock market

The effective dimension of stock market as defined in the preceding section d has been used to analyze the dynamics of crises on the market of all the stocks under consideration and on sectoral markets. Dynamics of crises were measured with stock market space distortion index defined by formula (7). For this purpose, a monthly (22-day) observation window was taken, on the basis of which index S was computed for all companies stock market and for sector-oriented markets. The value of this index at the point in time t was calculated on the basis of returns of the period $[t-21, t]$.

Index S for all companies is presented on fig. 2. To disregard all its peaks and to be able to focus only on the most prominent fluctuations, an index peak exceeding unity was considered significant. Such index peaks appear across seven periods.

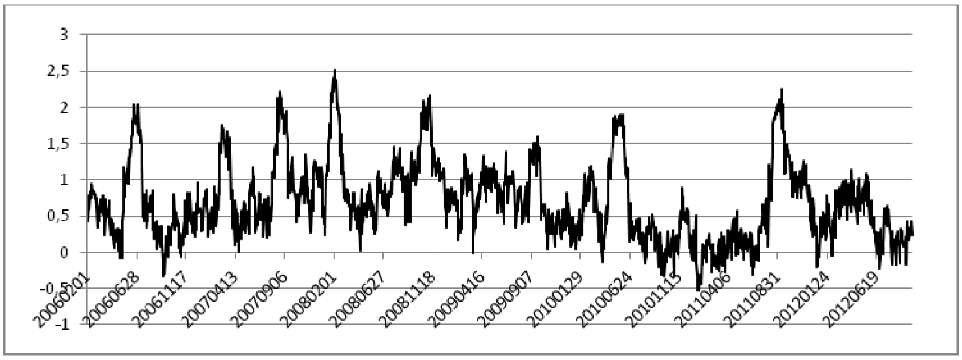

Fig. 2. The index *S* for all companies

In 2006, the first values of index S significantly exceeding unity were observed during the period from the end of May to mid-July. This was the period of the first perceivable adjustment of WSE and global stock exchange quotes against the growing tendency which had been present since 2003. At that time, the first symptoms of subprime credit crunch could already be observed, such as decreasing prices of real estate in the U.S.

The second of the highlighted periods occurred at the onset of subprime credit crunch – this is the period of first bankruptcies of financial institutions in the United States which had been offering these credits, led by the largest collapse of New Century Financial at the turn of February/March. Although these were clear symptoms of the approaching crisis, they were completely ignored by the financial markets while the boom on global stock exchanges continued for six more months. The peak of index S occurred in fact as a response to major decreases on the Chinese stock exchange of February 27, 2007, caused by a warning of approaching recession in the U.S., pronounced by Alan Greenspan, FED Chairman, at a conference in Hong Kong. This peak covers 22 values of the index and lasts until the observation window contained a return of that date.

The third peak of index S commenced in early August 2007 and lasted two months. This was the period of first declines on stock exchanges after achievement of global maximums by world indexes. Also in this period, first support programs emerged, targeted at Americans facing problems with repayment of their mortgages. First symptoms of banks' liquidity problems occurred in Europe as well (including the British Northern Rock).

The next, fourth, highest peak of the risk index was observed in the first two months of 2008. It occurred during the period when both the World Bank and FED were openly pointing to recession in the U.S. Colossal losses were also reported during that time by the largest financial institutions worldwide.

The following prominent leap of the index could be noticed on September 15, 2008 – exactly at the date of collapse of Lehman Brothers, a 158-years-old investment bank. This is definitely the most extensive period of S index values exceeding unity throughout the period of crisis. Considering the weight of that period's events, it would be labeled a "financial tsunami" or a "banking collapse". That period was immediately preceded by acquisition by FED of the two largest U.S. mortgage market institutions – Fannie May and Freddie Mac. Merrill Lynch was taken over by Bank of America, while AIG – America's largest insurer – was nationalized. During the same period, the crisis definitely spread to Europe. Benelux governments partially nationalized Fortis bank, the German government provided a multi-billion rescue package for Hypo Real Estate bank, the government of the Netherlands was rescuing ING Bank, and the next day the French government announced similar actions to be undertaken to rescue the six largest banks, including Crédit Agricole, BNP and Société Générale [see: Holzer, 2009]. All these incidents caused extremely high volatility on financial markets and common decline of indexes on all global stock exchanges. The intensity of that period's events was illustrated by the widest peak of index S throughout the duration of crisis. This not only confirms the ability of this measure to capture periods of market disruptions but also to measure their scale. Increased values of the risk index are observed for a year. The second express peak of the risk index was recorded at the end of that period, in September 2009. No special macroeconomic events were noted during that time, and the increase of the index value was related to correction of uninterrupted semiannual increases at global stock exchanges.

Next very clearly increased values of the index were observed during the debt crisis in Europe during the period from the end of April to mid-June 2010. This was a period of intensified struggle with debt crisis in Greece. During that period, aid programs for Greece were established and put into practice, while Greece itself undertook a budget for the upcoming years with multiple cuts and privatization plans in the country envisaged for the future.

The final period singled out by the index under consideration commences in the first week of August 2011. That week was started with Standard & Poor's publication of lowering the United States' highest credit rating for the first time in history. The first week of August became the worst week since the crash caused by Lehman Brothers' collapse at global stock exchanges. WIG20 lost over 10 percent in a week, and the scale of losses at the majority of stock markets worldwide was similar. Later, the problems with Italy's and Spain's debt emerged, along with a vision of Eurozone disintegration. That period took as much as two and a half months.

To study the effect of the distinguished phases of the subprime credit crunch and the European debt crisis on the specific sectors of the economy, the researchers would analyze the changes of indexes S for the market of studied companies, divided into specific sectors. Considering the companies from a single sector, a homogeneous collection of data was obtained, more prone to market shocks than a diversified collection of all companies. Financial and economic crises would affect companies from specific sectors with varying levels of force. T. Araújo and F. Louçă [2007] differentiated between a local crisis, which focuses only on selected sectors, and a global crisis that impacts the whole financial market. In this paper, two financial crises were analyzed and their various phases had a different influence on the specific sectors of the economy. Risk index for stocks of companies in the particular sectors is presented in fig. 3 and for the segments as such – in fig. 4.

The analyzed crises would present themselves strongest in the financial sector, they had a lesser impact force on companies from the industrial sector, and were least prominent in the utilities sector. During the 2006 adjustment of stock prices, similar market space distortion index behaviors were noticed for all the studied sectors and segments.

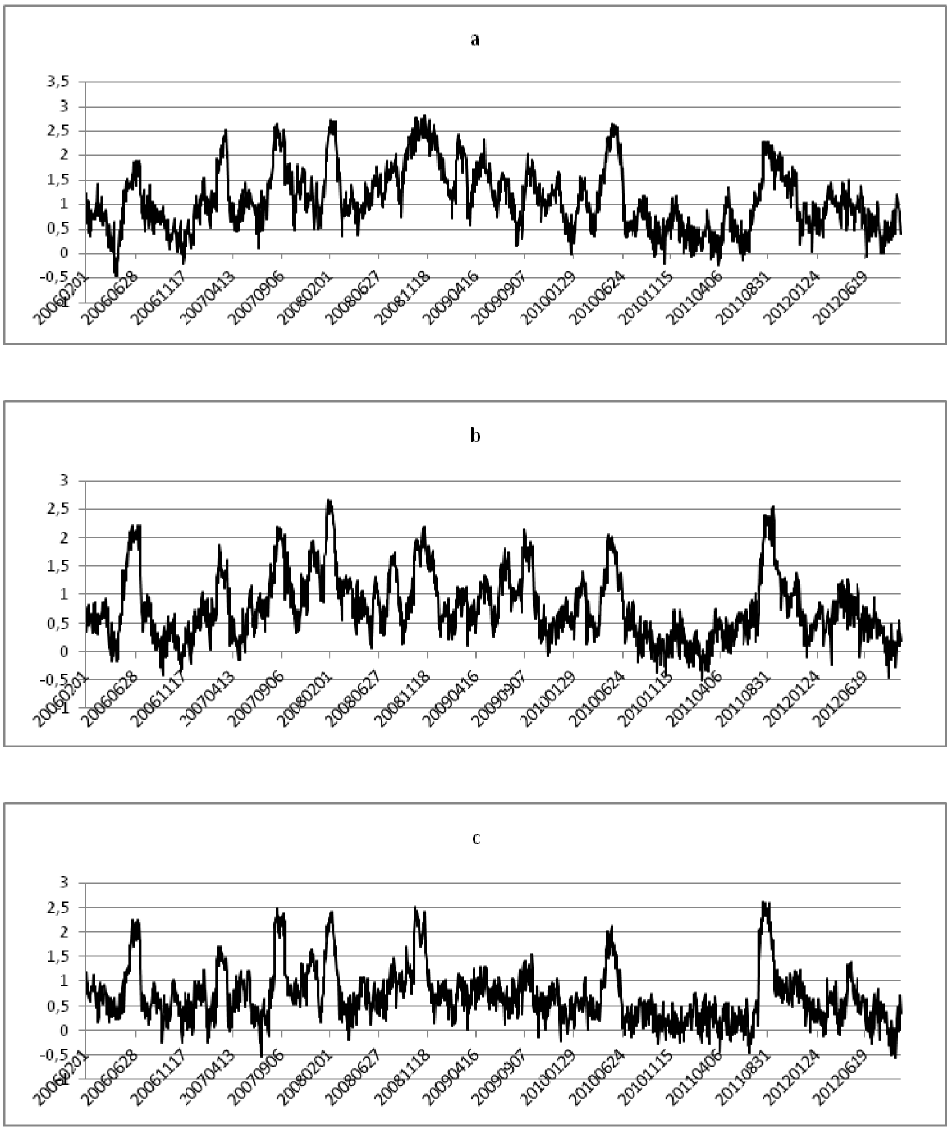

Fig. 3. The index *S* for: a) financial sector, b) industrial sector, c) utilities sector

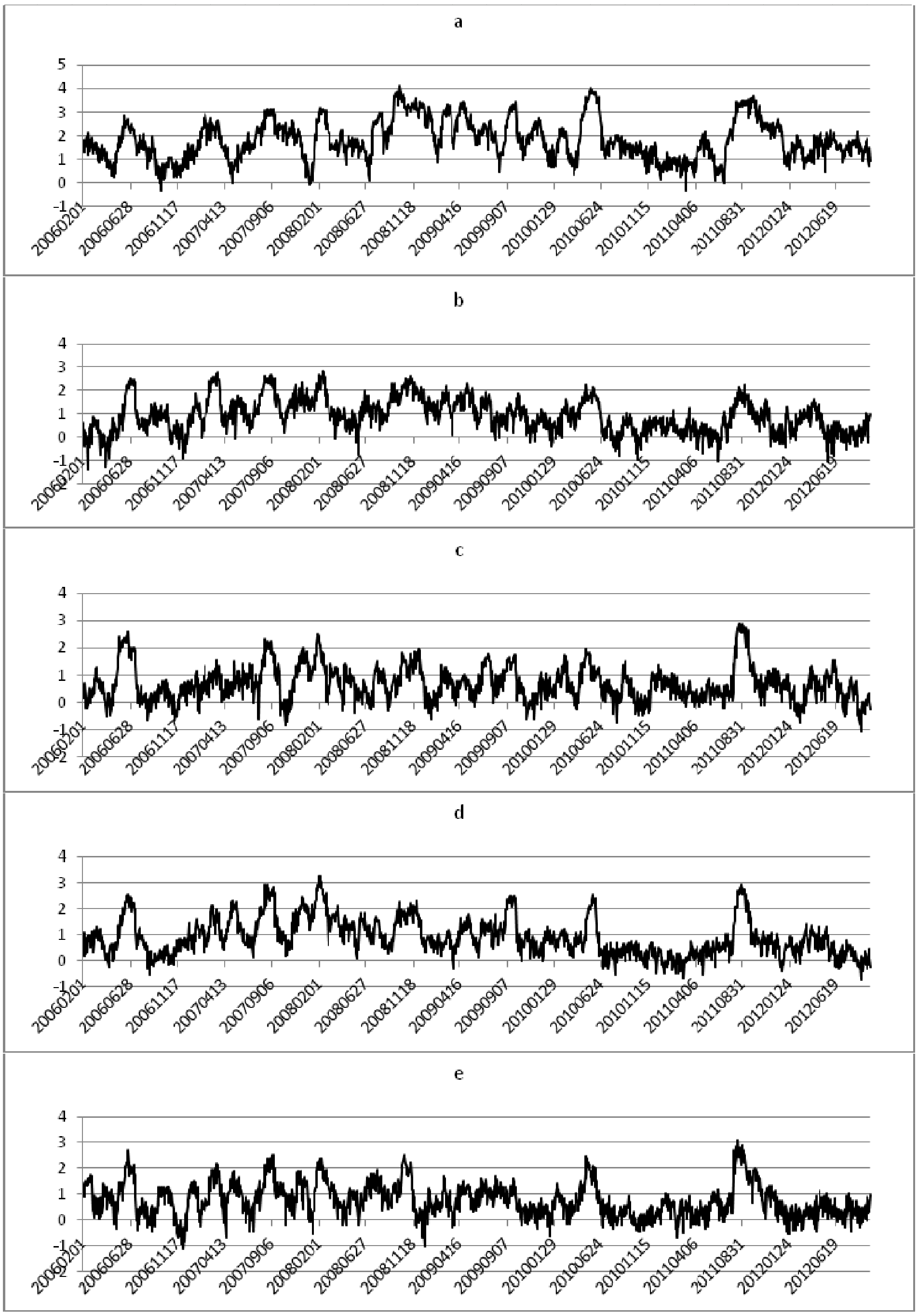

Fig. 4. Index *S* for companies in the following segments: a) banks, b) developers, c) FMCG, d) construction, e) IT

The risk index would clearly indicate the banking sector as the most affected by the subprime credit crisis and the European debt crisis in all their phases. This emphasizes the character of those crises that originated from this sector exactly – during 2007-2009 through toxic securities based on subprime credits securitization, and during 2010-2011 through Greek bonds held in portfolios of the largest European banks. Maximum values of the risk index for banks are highest in almost all the periods. An exception to this rule is the period from January to February 2008 where higher value of the index is observed for the construction segment. The value of the index for banks in the initial phase of crises, albeit predominant in comparison to other sectors, would only reveal the scale of risk for that sector after the Lehman Brothers crash.

This was not entirely supported by banks' bottom lines. EBIT and net profit in 2008 of all the banking sector companies listed at WSE increased by 8% and 11%, respectively, beyond the data of 2007. EBIT and net profit would only decrease in the following year, by 33% and 36%, respectively. Financial results of the sector improved in 2010-2011 – EBIT grew by 37% and 22%, respectively, while net profit increased by 37% and 33%, respectively [www 1].

The next sectors which were most strongly affected by the wave of crisis include developers and construction. Both these sectors certainly belong to those segments of the economy which are most sensitive to consequences of an economic slowdown. The first symptoms of slowdown in Poland would only be noticed in Q4 2008, GDP growth rate in that quarter was only 2.9% while its respective values in the first three quarters of that year were as follows: 6.0%, 5.8%, and 4.8% [Socha, Orłowski, Sękowski, 2009]. The same observations are confirmed by financial results of these sectors during that period. EBIT for both segments (WIG construction, WIG developers) Q4 2008 to Q4 2007 decreased by 34% and 35% for the developer and construction segment, respectively, while their net profits dropped in the same period by 83% and 32% [Socha, Orłowski, Sękowski, 2009]. EBIT for all construction sector companies listed at WSE throughout 2008 increased by 128% beyond the value of 2007. It increased again in 2009 by 16%. In the following years, EBIT drops were recorded, respectively: 12% in 2010, 28% in 2011, and 106% in H1 2012 [www 1]. EBIT for all developer sector companies listed at WSE throughout the period, except 2010, exhibited a negative trend. It decreased by 15% in 2008 and by 95% in the following year, YOY. It grew by 932% in 2010 to then decrease in 2011 by 78% and in H1 2012 by 63% [www 1]. It was exactly in the period from January to February 2008, when there was a mention of recession in U.S. economy, the indexes S for both these sectors would increase to the highest levels, even exceeding the level of the banking index for companies in the construction segment.

Utilities and FMCG sector companies would manage relatively well in times of crisis. This thesis is not only supported by low values of the indexes under consideration but also by financial results. EBIT for the FMCG sector (WIG FMCG) for Q4 2008 increased by 163% YOY [Socha, Orłowski, Sękowski, 2009]. Operating profit for all companies quoted at WSE from FMCG sector exhibited an increasing tendency during 2007-2011, but a decrease was recorded in H1 2012 [www 1]. Net profit of this sector dropped by 55% in 2008 as against the preceding year, while during 2009-2011 it would exhibit an increasing tendency – it grew by 107%, 206% and 33%, respectively. In the first half of 2012, net profit decreased by 14% [www 1]. However, the increase of the index for that sector at the end of 2011 was truly surprising. The index reached its highest value as compared to the preceding periods. This might have been caused by deterioration of the situation of companies in this sector as a result of increasing and volatile prices of FMCG raw materials, which present themselves in the bottom lines. Moreover, it may also be a result of investors' general tendency to retreat from developing markets in view of strengthening debt problems in Europe, which is illustrated by similar patterns of behavior of the index presenting stock market space distortion for all the sector-oriented markets under review in August and September 2011.

Conclusions

Modeling of financial markets' behavior must take account of the degree of their complexity, which is considered in the structure of relations between financial instruments. This complexity is further reinforced by the fact that markets during crash periods behave in an entirely different way than in "normal" periods. Increase of correlation during such periods presents itself in simultaneous decreases of prices of financial instruments. The concept of Euclidean metric between stocks as introduced by R.N. Mantegna [Mantegna, 1999; Mantegna, Stanley, 2000] offers a tool for analyzing the structure of relations on financial markets with the notions of geometry. Knowledge of distances between objects provides grounds for analyzing mutual relations between these objects. In papers [Araújo, Louçã, 2007, 2008b], T. Araújo and F. Louçã, developed a synthetic risk index on the ground of Euclidean distance, which allows for identification and interpretation of periods of market disruptions and analysis of their dynamics.

This paper presents results of empirical studies based on this method. Research was conducted on a sample of 73 companies listed at the Warsaw Stock

Exchange during the period from early 2006 to the end of September 2012. This is the period of financial crises: subprime credits and the European debt crisis, from their first symptoms until the time the present research was conducted. Completed research leads to several detailed conclusions. The risk index is a metric which proves effective in the conditions of the Polish capital market. It allows correct identification and analysis of the periods of greatest turbulence on financial markets. All the distinguished periods of market shocks had their source outside Poland, which emphasizes the global character of the Polish capital market and its dependency on global markets. Although stocks of companies would behave quite uniformly at crisis peaks, the risk would vary within the particular sectors. The banking sector was identified by the index as the most susceptible to the events of that period, followed by two more: construction and developers. These sectors are most strongly correlated to the dynamics of economic growth. It implies reasonableness of inter-sectoral diversification of investment portfolio and the possibility of using the index under review in construction of an investment strategy. However, it should be pointed out that the observed turbulences on financial markets do not correspond to financial results of all sectors, which may be due to Warsaw Stock Exchange's dependency on world stock exchanges and to the financial situation of foreign investors. It is alarming that in the last specified debt crisis in Europe, the risk index model in the banking sector resembled the worst wave of the subprime credit crunch that took place after Lehman Brothers' crash, while in 2012 – following that period – the risk index would still remain on an increased level. Therefore, it may not be ruled out that the index, like at that time in the past, is also now signaling enormous problems in real national and global economy in view of the current perturbations on financial markets.

Literature

Araújo T., Louçã F. (2004), *Complex Behavior of Stock Markets: Processes of Synchronization and Desynchronization during Drises*, arXiv:cond-mat/0403333v2.

Araújo T., Louçã F. (2007), *The Geometry of Crashes – A Measure of the Dynamics of Stock Market Crises*, „Quantitative Finance", Vol. 7, Iss. 1, s. 63-74.

Araújo T., Louçã F. (2008a), *The Dynamics of Speculative Markets: the Case of Portugal's PSI20*, Working Papers 2008, 34/2008/DE/UECE.

Araújo T., Louçã F. (2008b), *The Seismography of Crashes in Financial Markets*, „Physics Letters A", Vol. 372, s. 429-434.

Gower J.C. (1966), *Some Distance Properties of Latent Root and Vector Methods used in Multivariate Analysis*, „Biometrika", Vol. 53, No. 3-4, s. 325-338.

Holzer R. (2009), *Jak rozwijał się kryzys 2007-2009 – infografika, kalendarium*, www.obserwatorfinansowy.pl.

Just M. (2013), *Wpływ kryzysów na zniekształcenie przestrzeni rynku akcji z indeksu WIG20*, „Finanse, Rynki Finansowe, Ubezpieczenia", nr 63, s. 207-219.

Mantegna R.N. (1999), *Hierarchical Structure in Financial Markets*, „European Physics Journal B", Vol. 11, No. 1, s. 193-197.

Mantegna R.N., Stanley H.E. (2000), *An Introduction to Econophysics: Correlations and Complexity in Finance*, Cambridge University Press, Cambridge UK.

Mendes R.V., Araújo T., Louçã F. (2003), *Reconstructing an Economic Space from a Market Metric*, „Physica A", Vol. 323, No. 1, s. 635-650.

Onnela J.-P., Chakraborti A., Kaski K., Kertész J. (2002), *Dynamic Asset Trees and Portfolio Analysis*, „European Physics Journal B", Vol. 30, No. 3, s. 285-288.

Onnela J.-P., Chakraborti A., Kaski K., Kertész J. (2003), *Dynamic Asset Trees and Black Monday*, „Physica A", Vol. 324, No. 1-2, s. 247-252.

Rak R. (2008), *Ilościowe charakterystyki fluktuacji i korelacji na polskim rynku akcji*, rozprawa doktorska, Uniwersytet Rzeszowski.

Sandoval Junior L., De Paula Franca I. (2011), *Correlation of Financial Markets in Times of Crisis*, arxiv.org/abs/1102.1339v2.

Socha J., Orłowski W., Sękowski J. (2009), *Kryzys na rynkach finansowych*, PricewaterhouseCoopers 2009, www.pwc.pl.

Walesiak M., Gatnar E. (red.), 2009, *Statystyczna analiza danych z wykorzystaniem programu R*, Wydawnictwo Naukowe PWN, Warszawa.

[www 1] www.rgl.pl.

GEOMETRIA KRYZYSÓW NA RYNKU AKCJI NOTOWANYCH NA GIEŁDZIE PAPIERÓW WARTOŚCIOWYCH W WARSZAWIE

Streszczenie: W pracy zdefiniowano i zinterpretowano zmiany zachodzące w przestrzeni rynku akcji. Analizie poddano 73 spółki notowane na Giełdzie Papierów Wartościowych w Warszawie w okresie od początku 2006 r. do końca września 2012 r. Jest to okres obejmujący w całości dwie odsłony kryzysu finansowego – od pierwszych objawów kryzysu do momentu, kiedy te badania zostały przeprowadzone. Zbadano dynamikę rynku akcji za pomocą wskaźnika, który mierzy zmiany efektu zniekształcenia kształtu przestrzeni rynku. Indeks ten opiera się na metodach geometrii euklidesowej. Pozwala on na właściwą identyfikację i interpretację najbardziej burzliwych okresów na rynku finansowym.

Słowa kluczowe: rynek finansowy, analiza kryzysu, geometria, przestrzeń rynku.