Chapter 1
Homogeneity hypothesis testing for degree distribution in the market graph

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Abstract T

he problem of homogeneity hypothesis testing for degree distribution in the market graph is studied. Multiple hypotheses testing procedure is proposed and applied for China and India stock markets. The procedure is constructed using bootstrap method for individual hypotheses and Bonferroni correction for multiple testing. It is shown that homogeneity hypothesis of degree distribution for the stock markets for the period of 2003-2014 is not accepted.

Key words: Homogeneity hypothesis, degree distribution, market graph, bootstrap method, multiple hypotheses testing, Bonferroni correction

1.1 Introduction

Market graph was proposed in [2] as a tool for stock market analysis. The dynamic of the market graph for US stock market was studied in [4], where edges density, maximum cliques, and maximum independent sets of the market graph were considered. There are another characteristics of the market graph which are interesting in market network analysis. In the present paper we investigate the degree distribution of vertices in the market graph. From economic point of view, the degree of vertex characterizes the influence of the corresponding stock on the stock market. For example, the network topology structure as a star means the presence of a dominating stock. On the other hand, uniform distribution of degrees of vertices can be interpreted as a characteristic of ”free” market.

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In this paper we investigate the problem of stationarity of network topologies over time. The main question is: are there statistically significant differences in the topology of the market graphs for different periods of observation? The problem of homogeneity of degree distributions over time is considered as multiple testing problems of homogeneity hypotheses of degree distributions for each pairs of years. At the same time the problem of homogeneity hypotheses of degree distributions for pair of years is considered as multiple testing problem of homogeneity hypotheses for each vertex degree.

To test the homogeneity hypotheses for each vertex degree the method based on confidence intervals is applied. To construct confidence intervals the bootstrap method is used. In order to construct a multiple testing procedure with a given significance level we use Bonferroni corrections. The obtained procedure is applied to China and India stock markets for the period from 2003 to 2014 (twelve years). To conduct experiments 100 most liquid stocks are selected from each market.

The paper is organized as follows. In Section 2 a brief overview of the market graph approach is given. In Section 3 we formally state the problem. In Section 4 a detailed descriptions of the multiple testing statistical procedure for testing homogeneity hypotheses of degree distribution is given. In Section 5 the results of application of this procedure to Chinese and Indian stock market are presented. The Section 6 summarizes the main results of the paper.

1.2 Market graph model

Let N be the number of stocks on the stock market. Let $p_i(t)$ be the price of the stock i for the day t, and $r_i(t)$ be the log return of the stock i for the day t:

$$r_i(t) = \log \frac{p_i(t)}{p_i(t-1)}$$

We assume that $r_i(t)$ are observations of the random variables $R_i(t)$, random variables $R_i(t), ,t = 1,2,\ldots,n$ are independent and identically distributed as R_i for fixed i, and random vector $(R_1, R_2, \ldots, R_N)$ has a multivariate normal distribution with correlation matrix $||\rho_{i,j}||$.

Let

$$r_{i,j} = \frac{\Sigma(r_i(t)-\overline{r_i})(r_j(t)-\overline{r_j})}{\sqrt{\Sigma(r_i(t)-\overline{r_i})^2}\sqrt{\Sigma(r_j(t)-\overline{r_j})^2}}$$

be the estimated value of correlation coefficient between returns of the stocks i and j, where

$$\overline{r_i} = \frac{1}{n}\sum_{t=0}^{n} r_i(t)$$

Matrix $||\rho_{i,j}||$ is used to construct a true market graph, while matrix $||r_{i,j}||$ is used to construct a sample market graph. The procedure of the market graph construction is the following. Each vertex represents a stock. An edge connects two vertices i and

j, if $||\rho_{i,j}|| > \rho_0$ in case of the true market graph, and if $||r_{i,j}|| > r_0$ (where ρ_0, r_0 are threshold values) in case of the sample market graph. When the vertices share a common edge, they are called adjacent.

1.3 Problem statement

For a market graph on N vertices one can assocciate the following two-dimensional array:

$$\begin{array}{cccc} 0 & 1 & \dots & N-1 \\ v_0 & v_1 & \dots & v_{N-1} \end{array} \tag{1.1}$$

where line 1 represents the degree of vertices and the line 2 represents the number of vertices of the given degree. Denote by F_v the vector of degree distribution of vertices, $F_v = (v_0, v_1, \dots, v_{N-1})$.

Let L be the number of different periods of observations. The hypothesis of homogeneity of degree distributions over L periods of observations can be written as:

$$H_0 : F_v^1 = F_v^2 = \dots = F_v^L \tag{1.2}$$

where F_v^l is the distribution of vertex degrees for the period of observation$l$, $l = 1, 2, \dots, L$

The problem of testing H_0 could be considered as multiple testing problem for individual homogeneity hypotheses:

$$h^{k,l} : F_v^k = F_v^l, \;\; k, l = 1, 2, \dots, L, \;\; k \neq l \tag{1.3}$$

The hypothesis $h^{k,l}$ is the homogeneity hypothesis of degree distributions for the pair of years k and l. Hypothesis H_0 can be presented as the intersection of hypotheses $h^{k,l}$:

$$H_0 = \bigcap_{k,l=1,2,\dots,L,k\neq l} h^{k,l}$$

In this case, hypothesis H_0 is accepted if and only if all individual hypotheses $h^{k,l}$ are accepted, and hypothesis H_0 is rejected if at least one individual hypothesis $h^{k,l}$ is rejected.

The problem of testing individual hypothesis $h^{k,l}$ (homogeneity hypotheses of degree distributions for the pair of years k and l) can be considered as multiple testing problem of individual homogeneity hypotheses for each vertex degree:

$$h_j^{k,l} : v_j^k = v_j^l, \quad j = 0, 1, 2, \dots, N-1$$

One can consider the hypothesis $h^{k,l}$ as the intersection of individual hypotheses $h_j^{k,l}$

$$h^{k,l} = h_0^{k,l} \cap h_1^{k,l} \dots \cap h_{N-1}^{k,l}$$

In this case, hypothesis $h^{k,l}$ is accepted if and only if all individual hypotheses $h_j^{k,l}$, $j = 0,1,2,\ldots,N-1$ are accepted, and hypothesis $h^{k,l}$ is rejected if at least one individual hypothesis $h_j^{k,l}$ is rejected.

1.4 Statistical procedure for homogeneity hypotheses testing

Consider the individual hypotheses of the following form:

$$h^{k,l} : F_\nu^k = F_\nu^l \tag{1.4}$$

Let R^k, R^l be random vectors of distributions of stock returns for the periods k and l respectively. In order to test (1.4) we use two sequences of n_1 and n_2 observations of random vectors R^k and R^l (in what follows we suppose for simplicity $n_1 = n_2 = n$):

$$\begin{pmatrix} r_1^k(1) \\ r_2^k(1) \\ \cdots \\ r_N^k(1) \end{pmatrix} \begin{pmatrix} r_1^k(2) \\ r_2^k(2) \\ \cdots \\ r_N^k(2) \end{pmatrix} \cdots \begin{pmatrix} r_1^k(n) \\ r_2^k(n) \\ \cdots \\ r_N^k(n) \end{pmatrix} \tag{1.5}$$

$$\begin{pmatrix} r_1^l(1) \\ r_2^l(1) \\ \cdots \\ r_N^l(1) \end{pmatrix} \begin{pmatrix} r_1^l(2) \\ r_2^l(2) \\ \cdots \\ r_N^l(2) \end{pmatrix} \cdots \begin{pmatrix} r_1^l(n) \\ r_2^l(n) \\ \cdots \\ r_N^l(n) \end{pmatrix} \tag{1.6}$$

Where $r_i^k(t)$ is the return of the stock i in the day t for the year k and $r_i^l(t)$ is the return of the stock i in the day t for the year l.

Using these observations we construct the sample market graphs with a given threshold for the periods k and l and calculate its degree distributions. We use these sample degree distributions to construct individual test for hypothesis $h_j^{k,l}$. The individual test for $h_j^{k,l}$ will use a confidence intervals for ν_j^k and ν_j^l. To construct these confidence intervals we apply bootstrap procedure [5] in the following way:

1. Apply S times the statistical bootstrap procedure for each sequence of observations (1.5) and (1.6).
2. For each bootstrap sample, calculate the sample market graph and find the number of vertices of degree j in the sample market graph.
3. Calculate α-confidence interval for the number of vertices with degree j .

To take the decision for the hypothesis $h_j^{k,l}$ we use the following procedure: if the confidence intervals for ν_j^k and ν_j^l do not intersect, then the hypothesis is rejected. Otherwise it is accepted. Individual hypothesis $h^{k,l}$ is accepted if all hypotethes $h_j^{k,l}$, $j = 0,1,2,\ldots,N-1$ are accepted. Finally. the hypothesis H_0 is accepted if all hypotheses $h^{k,l}$ are accepted.

Let us introduce some notations. Define indicator of vertex degree in a sample graph as follows ($i = 1,2,\dots,N,\ j = 0,1,\dots,N-1$):

$$\chi_{i,j} = \begin{cases} 1, \text{if vertex } i \text{ has degree } j \\ 0, \text{otherwise} \end{cases} \tag{1.7}$$

Distribution of vertex degrees in one of bootstrap samples q ($q = 1,2,\dots,S$) for the period of observation k is defined by:

$$v_0^k(q), v_1^k(q), \dots, v_{N-1}^k(q)$$

with

$$v_j^k(q) = \sum_{i=1}^{N} \chi_{i,j}^k(q)$$

Using asymptotic normal approximation one can write the test for the hypothesis $h_j^{k,l}$ in the following form

$$\varphi_j^{k,l} = \begin{cases} 0, \text{ if } |\overline{v}_j^k - \overline{v}_j^l| < c(\alpha')(\sigma(v_j^k) + \sigma(v_j^l)) \\ 1, \text{ otherwise} \end{cases} \tag{1.8}$$

where

$$\overline{v}_j^k = \frac{1}{S}\sum_q v_j^k(q), \quad \overline{v}_j^l = \frac{1}{S}\sum_q v_j^l(q)$$

and $c(\alpha')$ is $(1-\alpha')$-two size quantile of standard normal distribution. For example, for $\alpha' = 0,05 \quad c_{\alpha'} = 0,98$.

When we deal with hypothesis $h^{k,l}$ we face with the multiple testing problem of homogeneity hypotheses for each vertex degree. To control the probability of first type error Bonferroni correction is used. This means that significance level α' for hypothesis $h_j^{k,l}$ is chosen as follows $\alpha' = \alpha/100$, where α is the significance level of the resulting test for the hypothesis $h^{k,l}$. To test the hypothesis H_0 with the probability of the first type error α one has to choose the the error rate for the tests $\phi_j^{k.l}$ equal to $\alpha'' = \alpha/(100 * C_L^2)$ (double Bonferroni correction).

1.5 Experimental results

The experiments are conducted on the basis of data from the stock markets of China and India. The 100 most traded stocks for the period from 01 January 2003 to 31 December 2014 are considered. The number of observed days $n = 250$ (1 calendar year). The results are shown in the tables below.

In each table element (k,l) is equal to zero if the hypothesis $h^{k,l}$ is accepted and equal to 1 otherwise. Table 1 - Table 6 present the results for a different values of threshold for Chinese stock market. Table 7 - Table 12 present the results for a different values of threshold for Indian stock market. One can see that pairwise hypotheses of homogeneity are mostly rejected. If the value of threshold is increasing then more and more homogeneity hypotheses are accepted.

Pairwise hypotheses of homogeneity mainly rejected. However, there are two years (2003,2007) for which the homogeneity hypotheses are accepted for selected values of threshold. For (2003,2013) there are thresholds for which the homogeneity hypotheses are accepted and are rejected.

1.6 Conclusions

In this paper we investigated the homogeneity od degree distribution in the market graph over time. The procedure of comparison of degree distributions for different periods of observation was built to study this problem. This procedure has been applied to the real data yields the 100 most traded shares for Chinese and Indian stock markets. Conducted experiments show that vertex degree distribution is not stationary and significantly changes over the time.

Acknowledgements The work of Koldanov P.A. was conducted at the Laboratory of Algorithms and Technologies for Network Analysis of National Research University Higher School of Economics. The work is partially supported by RFHR grant 15-32-01052.

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Table 1.1 Threshold=0.2, Chinese market. 0 - acceptance of hypothesis, 1 - rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	0	1	0	1	1	1	1	1	0	1
2004	1	0	0	1	1	1	1	1	1	1	1	1
2005	0	0	0	1	1	1	1	1	1	1	1	1
2006	1	1	1	0	1	1	1	1	0	1	1	1
2007	0	1	1	1	0	1	1	1	1	1	1	1
2008	1	1	1	1	1	0	1	0	0	1	1	1
2009	1	1	1	1	1	1	0	1	1	1	1	1
2010	1	1	1	1	1	0	1	0	0	1	1	1
2011	1	1	1	0	1	0	1	0	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	0	1
2013	0	1	1	1	1	1	1	1	1	0	0	1
2014	1	1	1	1	1	1	1	1	1	1	1	0

Table 1.2 Threshold=0.3, Chinese market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	0	1	0	1	1	1	1	1	0	1
2004	1	0	0	1	1	1	1	1	1	1	1	1
2005	0	0	0	1	1	1	1	1	1	1	1	1
2006	1	1	1	0	1	1	1	1	0	1	1	1
2007	0	1	1	1	0	1	1	0	1	1	1	1
2008	1	1	1	1	1	0	1	0	0	1	1	1
2009	1	1	1	1	1	1	0	1	1	1	1	1
2010	1	1	1	1	0	0	1	0	0	1	1	1
2011	1	1	1	0	1	0	1	0	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	0	1
2013	0	1	1	1	1	1	1	1	1	0	0	1
2014	1	1	1	1	1	1	1	1	1	1	1	0

Table 1.3 Threshold=0.4, Chinese market. 0 - acceptance of hypothesis, 1 - rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	0	1	1	1	1	1	1	1
2004	1	0	0	1	1	1	1	0	1	1	1	0
2005	1	0	0	1	0	1	0	0	1	1	1	0
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	0	1	0	1	0	1	1	1	1	1	0	0
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	1	0	1	1	1	0	1	1	1	1	1
2010	1	0	0	1	1	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	1	1	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	1	1
2013	1	1	1	1	0	1	1	1	1	1	0	1
2014	1	0	0	1	0	1	1	1	1	1	1	0

Table 1.4 Threshold=0.5, Chinese market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	0	1	0	1	1	1	0	0
2004	1	0	0	1	1	1	0	1	1	1	1	1
2005	1	0	0	1	1	1	1	0	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	0	1	1	1	0	1	1	1	1	1	1	0
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	0	0	1	1	1	1	0	1	1	1	0	0
2010	1	1	0	1	1	1	1	0	1	1	1	0
2011	1	1	1	1	1	1	1	1	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	1	1
2013	0	1	1	1	1	1	0	1	1	1	0	1
2014	0	1	1	1	0	1	0	0	1	1	1	0

Table 1.5 Threshold=0.6, Chinese market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	0	1	0	1	1	1	0	0
2004	1	0	0	1	1	1	0	1	1	1	1	1
2005	1	0	0	1	1	1	1	0	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	0	1	1	1	0	1	1	1	1	1	1	0
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	0	0	1	1	1	1	0	1	1	1	0	0
2010	1	1	0	1	1	1	1	0	1	1	1	0
2011	1	1	1	1	1	1	1	1	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	1	1
2013	0	1	1	1	1	1	0	1	1	1	0	1
2014	0	1	1	1	0	1	0	0	1	1	1	0

Table 1.6 Threshold=0.7, Chinese market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	0	1	1	0	1	1	1	0	1	1	1
2004	0	0	0	0	0	1	1	1	0	1	1	1
2005	1	0	0	0	0	1	1	1	0	1	1	1
2006	1	0	0	0	0	1	1	1	0	1	1	1
2007	0	0	0	0	0	1	1	1	0	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	1	1	1	1	1	0	0	1	1	0	0
2010	1	1	1	1	1	1	0	0	1	1	0	0
2011	0	0	0	0	0	1	1	1	0	1	1	1
2012	1	1	1	1	1	1	1	1	1	0	0	0
2013	1	1	1	1	1	1	0	0	1	0	0	0
2014	1	1	1	1	1	1	0	0	1	0	0	0

Table 1.7 Threshold=0.2, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	1	1	1	1	1	1	1	1
2004	1	0	1	1	1	1	1	1	1	1	1	1
2005	1	1	0	1	1	1	0	1	1	1	1	1
2006	1	1	1	0	1	1	0	1	1	1	1	1
2007	1	1	1	1	0	1	1	1	1	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	1	0	0	1	1	0	1	0	0	0	1
2010	1	1	1	1	1	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	0	1	0	0	1	1
2012	1	1	1	1	1	1	0	1	0	0	0	1
2013	1	1	1	1	1	1	0	1	1	0	0	1
2014	1	1	1	1	1	1	1	1	1	1	1	0

Table 1.8 Threshold=0.3, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	1	1	1	1	1	1	1	1
2004	1	0	1	1	1	1	1	1	1	1	1	1
2005	1	1	0	1	1	1	1	1	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	1	1	1	1	0	1	1	1	1	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	1	1	1	1	1	0	1	1	1	0	1
2010	1	1	1	1	1	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	1	1	0	0	1	0
2012	1	1	1	1	1	1	1	1	0	0	0	1
2013	1	1	1	1	1	1	0	1	1	0	0	0
2014	1	1	1	1	1	1	1	1	0	1	0	0

Table 1.9 Threshold=0.4, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	1	1	1	1	1	1	1	1	1	1
2004	1	0	1	1	1	1	1	1	1	1	0	1
2005	1	1	0	1	1	1	1	1	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	1	1	1	1	0	1	1	1	1	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	1	1	1	1	1	0	1	1	1	0	1
2010	1	1	1	1	1	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	1	1	0	0	0	0
2012	1	1	1	1	1	1	1	1	0	0	0	0
2013	1	0	1	1	1	1	0	1	0	0	0	0
2014	1	1	1	1	1	1	1	1	0	0	0	0

Table 1.10 Threshold=0.5, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	0	1	1	1	1	1	1	1	1	1
2004	1	0	1	1	1	1	0	1	1	1	1	0
2005	0	1	0	1	1	1	1	0	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	1	1	1	1	0	1	1	0	1	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	0	1	1	1	1	0	1	0	1	1	1
2010	1	1	0	1	0	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	0	1	0	1	0	0
2012	1	1	1	1	1	1	1	1	1	0	0	0
2013	1	1	1	1	1	1	1	1	0	0	0	0
2014	1	0	1	1	1	1	1	1	0	0	0	0

Table 1.11 Threshold=0.6, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	0	1	1	1	1	1	1	1	1	1
2004	1	0	1	1	1	1	0	1	1	1	1	0
2005	0	1	0	1	1	1	1	0	1	1	1	1
2006	1	1	1	0	1	1	1	1	1	1	1	1
2007	1	1	1	1	0	1	1	0	1	1	1	1
2008	1	1	1	1	1	0	1	1	1	1	1	1
2009	1	0	1	1	1	1	0	1	0	1	1	1
2010	1	1	0	1	0	1	1	0	1	1	1	1
2011	1	1	1	1	1	1	0	1	0	1	0	0
2012	1	1	1	1	1	1	1	1	1	0	0	0
2013	1	1	1	1	1	1	1	1	0	0	0	0
2014	1	0	1	1	1	1	1	1	0	0	0	0

Table 1.12 Threshold=0.7, Indian market. 0 acceptance of hypothesis, 1 rejection of hypothesis.

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
2003	0	1	0	0	0	1	1	0	0	1	1	1
2004	1	0	1	0	1	0	0	1	0	0	1	0
2005	0	1	0	1	0	1	1	0	0	1	1	1
2006	0	0	1	0	1	0	0	1	0	0	0	0
2007	0	1	0	1	0	1	1	0	0	1	1	1
2008	1	0	1	0	1	0	0	1	1	0	1	1
2009	1	0	1	0	1	0	0	1	0	0	1	1
2010	0	1	0	1	0	1	1	0	0	1	1	1
2011	0	0	0	0	0	1	0	0	0	0	1	1
2012	1	0	1	0	1	0	0	1	0	0	0	0
2013	1	1	1	0	1	1	1	1	1	0	0	0
2014	1	0	1	0	1	1	1	1	1	0	0	0