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POLISH UNIVERSITIES OF ECONOMICS IN EUROPEAN NETWORKS

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Abstract: In recent years, the evaluation of research conducted in European universities has become a significant problem. The growing concern for the quality and evaluation of research conducted at universities highlights the importance of university rankings, especially global rankings. The aim of the paper is to identify the network system of Polish universities of economics among their European counterparts belonging to the same networks, and indicate the positions of Polish universities within these networks. The study used a network approach to analyse the connections of European universities using university networks. The networks enable the visualization of complex, multidimensional data and provide statistical indicators for interpreting the resultant graphs. The analysis is exploratory in its nature and uses visualisation techniques of social network analysis (SNA), multidimensional scaling

(MDS), principal component analysis (PCA), and Eigen-model network analysis (ENA). The analysis covered 150 universities of economics in Europe and 11 university networks. Network analyses were performed with the R program. The paper presents different methods that allowed for the identification of network systems of Polish economic universities within the networks of European universities. An analysis of the social networks based on network indicators was also included.

Keywords: principal component analysis (PCA), multidimensional scaling (MDS) , network analysis, European universities.

1. Introduction

In recent years the evaluation of research conducted in European universities has become a significant problem. The widely disseminated results of these studies are believed to be the main factor influencing economic performance. Universities and their interconnections, roles in education, research and innovation, are considered to be a major factor in the success of the Lisbon strategy towards a global knowledge--based economy. Improving the capacity and quality of university research is essential for social innovation. The economic dimension of university research and the increased spending on this research contribute to the strengthening and concern for the quality and excellence of research, accountability, transparency, comparability and competition, as well as performance indicators and ratings. The growing concern for the quality and evaluation of research conducted at universities highlights the importance of university rankings, especially global rankings. The overall performance of universities is closely related with their ability of cooperation and networking. The authors represent the field of economic and managerial sciences, whose development is highly dependent on co-working and the establishment of long-lasting relationships with European partner universities. Although there are some studies concerning the analysis of networking among universities (Farré--Perdiguer, Sala-Rios, and Torres-Solé, 2016; Romero and Costa, 2016), there is still very limited information and research on university networking and especially the interconnectedness of Polish state-owned economic universities (Katowice, Kraków, Wrocław, Poznań and Warszawa) within European scientific networks of universities of economics.

The aim of the paper is to identify the network system of Polish universities of economics among their European counterparts belonging to the same networks and indicate the positions of Polish universities within these networks. The specific research questions are as follows:

1. What is the overall structure of the network of universities of economics?
2. What are the sub-networks within the network structure?
3. Which universities take central and peripheral positions in the network?
4. What is the structure of the ego-networks of Polish universities of economics?
5. What is the spatial interconnectedness of Polish universities of economics?

6. What are the differences between the network visualizations across the methods applied?

The analysis is exploratory in its nature and uses visualisation techniques of social network analysis (SNA), multidimensional scaling (MDS), principal component analysis (PCA), and Eigen-model network analysis (ENA). The choice of methods was related to the specificity of the assumptions and the nature of the input matrix. For SNA the adjacency matrix was used, MDS was based on the distance matrix, PCA explored the interrelations in reduced space on the correlation matrix, whereas ENA used the weights matrix. Due to the limited scope of research findings and exploratory character of the analytical techniques, no research hypothesis were formulated. The position of universities of economics within the network structure is based on network indicators for individual universities.

The study used a network approach to analyse the connections of European universities using university networks. Networks enable the visualization of complex, multi-dimensional data and provide statistical indicators for the interpretation of the resultant charts. Networks consist of nodes that are connected by edges, each has a weighting which determines the strength of the respective connection and the edges may or may not be facing. In most networking applications, nodes represent entities. However, it is natural to represent variables in statistical analysis as nodes. This representation has a long tradition in econometrics and psychometrics (Bollen and Lennox 1991; Edwards and Bagozzi, 2000)) and has become a driving force in the development of graphical models for causal analysis (Pearl, 2000). Relationships between variables (e.g. correlations) are expressed as weighted edges of the entire structure. Such dependencies are difficult to isolate by other means. Overall, the network approach makes it possible for the researcher to present complex statistical patterns in clear images, often without data reduction methods.

Network analyses were performed with the R program using the following packages: qgraph, networktools.

The aim of the article was to identify the network systems of Polish universities of economics compared to others European universities. An analysis of social networks based on network indicators is presented.

2. Networking of European universities of economics

For some time there have been various types of university rankings which have become more and more important. The appearance of a university in the global ranking usually means good standards and methods. The most popular ranking is The Shanghai Jiao Tong University Rankings called the Shanghai List (Aguillo, Bar-Ilan, Levene, and Ortega, 2010; Dominiak, Mercik, and Szymańska, 2012; Marginson, 2007). This index does not measure the quality of teaching, because it is extremely difficult to measure, but it is based on the results of a given university. This ranking has been published since 2003, presenting a list of the 500 best universities.

The Times Higher Education Supplement University Rankings is another popular ranking, published by The Times magazine. Both rankings assess the academic research of university employees: citations and points allocated for articles in leading scientific journals. According to the Shanghai List, the best five European economic universities in 2020 were:

1. London School of Economics and Political Science (UK).
2. University of Cambridge (UK).
3. University of Oxford (UK).
4. University College London (UK).
5. University of Toulouse I (France).

According to the Times Higher Education Supplement University Rankings, the best five in 2020 were:

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2. University of Cambridge (UK).
3. London School of Economics and Political Science (UK).
4. Eidgenössische Technische Hochschule Zurich ETH (Switzerland).
5. University College London (UK).

The oldest university in the English-speaking world is the University of Oxford, which is also the second oldest university in the world. The exact date of its establishment is unknown, yet teaching reportedly had started there in 1096. The university consists of 44 colleges and over 100 libraries, which means it is the largest library system in the United Kingdom. The number of students is around 22,000, of which 40 percent are from abroad, representing 140 countries.

The University of Cambridge was founded in 1209 and is a collegiate public research institution. It is the fourth oldest functioning university and the second oldest university in the English-speaking world. Over 18,000 students from all cultures and corners of the world attend Cambridge. About 4,000 students come from abroad, from over 120 different countries. In addition, international summer university schools offer 150 courses for students from 50 countries. The university is divided into 31 autonomous colleges in which students study in small groups. There are six schools at university colleges with approximately 150 faculties. These schools include arts and humanities, biological sciences, clinical medicine, humanities and social sciences, physical sciences and technology.

The London School of Economics and Political Science (LSE) is one of the world's leading universities in social sciences, specializing in many disciplines of social sciences, including economics, politics, sociology, law and anthropology. It was founded in the late 1800's by members of the Fabian Society Beatrice and Sidney Webb, Graham Wallas and George Bernard Shaw, with the aim of improving society, "by studying poverty and analyzing inequality." The LSE is world famous, home to 9,600 full-time students from approximately 140 countries, maintains international partnerships with Columbia University in New York, Sciences Po in Paris, Peking University in Beijing, the National University of Singapore and the University of Cape Town.

ETH Zurich was founded in 1855 as the Federal Polytechnic School, now called the Swiss Federal Institute of Technology in Zurich (or Poly for short), is considered one of the most prestigious universities in science and technology. This university based its success on the Swiss traditions of cultivating the principles of freedom, individual responsibility, the entrepreneurial spirit and an open approach to education. It contains 16 faculties that conduct academic interdisciplinary research in the fields ranging from architecture and biology to chemistry and physics.

University College London was founded in 1826 to provide higher education to those who otherwise did not have this opportunity. In 1878, it was the first university in England to accept women on an equal footing with men. UCL is a university college at the University of London and a member of the Russell Group. It employs approximately 850 professors and over 6,000 academic and research staff, and comprises 11 faculties: humanities, built environment, brain sciences, engineering, mathematical and physical sciences, law, natural sciences, Institute of Education, medical sciences, population health sciences as well as social and historical sciences.

The Federal University of Toulouse Midi-Pyrénées is an association of universities and research institutions based in the central Pyrenees. It was created by the Paris Treaty in 1229 by Count Raymond VII, who was obliged to finance local theological education. In 1969 the University of Toulouse was divided into three universities and became known as the Federal University of Toulouse Midi-Pyrénées. In 2007 the University of Toulouse research and higher education center was established, and in 2015 the Act on Higher Education and Research transformed the Federal University into ComUE. It has no campus, but more than 100,000 students are spread across 14 institutions: Toulouse I University Capitole, University of Toulouse II – Le Mirail, Paul Sabatier University, National Polytechnic Institute of Toulouse, Institut national des sciences appliquées de Toulouse, Institut supérieur de l'aéronautique et de l'espace, Institut d'études politiques de Toulouse, Jean-François Champollion University Center for Teaching and Research, École des Mines d'Albi-Carmaux, École nationale de l'aviation civile, École nationale supérieure d'architecture de Toulouse, École nationale de formation agronomique, Toulouse Business School and Institut Catholique d'Arts et Métiers.

All these colleges have a long history and university traditions, most of which originated from the United Kingdom.

Universities create networks of universities cooperating with each other, which positively affects their position. An example of a network is the European Network for Training in Economic Research called ENTER, which is a cooperative venture between eight leading European universities of economics:

- Barcelona – Universitat Autonoma de Barcelona,
- Brussels – Université Libre de Bruxelles,
- London – University College London,
- Madrid – Universidad Carlos III de Madrid,
- Mannheim – Universität Mannheim,

- Stockholm – University of Stockholm & Stockholm School of Economics,
- Tilburg – Tilburg University,
- Toulouse – Université de Toulouse I.

ENTER aims to support economic research and strengthen interaction between young researchers and regulators from various institutions. Under the supervision of professors from the home university, ENTER participants benefit from exchanges with researchers from the host university. Thanks to this they gain access to a much larger group of scientists.

The ENTER network enables conducting doctoral studies. Students can join the partner institution for the first year classes or for the stage of writing the thesis. The network allows students to obtain a double degree. The ENTER Research Master programmes in Brussels, Madrid, Mannheim, Stockholm and Toulouse are a two--year programme that in the first year offers a set of core courses and optional courses in the second year. In the second year, the student takes part in field courses and writes a Master's thesis. All courses are English-language.

The European Master in Labor Studies (EMLS) was established at the end of 1993. The network currently consists of 14 members from among the best universities in the European Union:

- Belgique / Belgien – Université catholique de Louvain,
- Deutschland – Universität Bremen, Universität Trier,
- England – London School of Economics, University of Warwick,
- España – Universitat Autònoma de Barcelona,
- France – Université Toulouse 1 Capitole,
- Ireland – University College Dublin,
- Italia – Università degli Studi di Firenze, Università degli Studi di Milano,
- Nederland – University of Amsterdam,
- Portugues – Instituto Universitario de Lisboa,
- România – National University of Political Studies and Public Administration,
- Slovenija – Univerza v Ljubljani.

The network trains new professionals who plan a career in the field of work and employment, employment relations or human resource management, in international companies, employment agencies, European organizations, etc.

The article presents 11 European university networks that include state-owned Polish economic universities:

1. EFMD (https://www.efmdglobal.org),
2. PRME (https://www.unprme.org),
3. PIM (https://pimnetwork.org),
4. CEEMAN (http://www.ceeman.org),
5. EUA (https://eua.eu),
6. CESEENET (https://www.cesee.net),
7. MAGNACARTA (http://www.magna-charta.org),
8. CEMS (https://www.cems.org),

9. EDAMBA (http://www.edamba.eu),
10. NICE (https://www.nicenetwork.uk),
11. ATLAS (https://www.atlasnetwork.org).

EFMD is a global non-profit management development organization. It is internationally recognized as an accreditation body for business schools, business school programs, and corporate universities. It has 900 members in 91 countries. In Europe, it comprises 515 centers, including 352 business schools. The organization's headquarters are in Brussels, Belgium, with offices in Geneva, Hong Kong, Miami and Prague.

With a network of 30,000 management professionals from academia, business, utilities and consulting companies, it plays a central role in shaping a global approach to managerial education. EFMD provides a unique forum for information, research, networking and debate on innovation and best practice. EFMD is a network that connects companies and academic institutions and facilitates and strengthens the exchange between them.

The Principles for Responsible Management Education (PRME) is a network founded in 2007 and supported by the United Nations. It is a platform that raises the importance of sustainable development in schools around the world. PRME gathers over 800 signatories globally, which has become the largest organized relationship between the United Nations and management-related higher education institutions.

PRME signatories gain access to local and global learning communities that work on projects addressing the complex challenges facing business in the 21st century. PRME encourages business schools and higher education institutions related to management to incorporate the values of business responsibility and sustainability into their activities, research and teaching using the following six principles:

- Principle 1 | Purpose
  We will develop the capabilities of students to be future generators of sustainable value for business and society at large and to work for an inclusive and sustainable global economy.
- Principle 2 | Values
  We will incorporate into our academic activities, curricula, and organizational practices the values of global social responsibility as portrayed in international initiatives such as the United Nations Global Compact.
- Principle 3 | Method
  We will create educational frameworks, materials, processes and environments that enable the effective learning experiences for responsible leadership.
- Principle 4 | Research
  We will engage in conceptual and empirical research that advances our understanding about the role, dynamics, and impact of corporations in the creation of sustainable social, environmental and economic value.

- Principle 5 | Partnership
  We will interact with managers of business corporations to extend our knowledge of their challenges in meeting social and environmental responsibilities and to explore jointly effective approaches to meeting these challenges.
- Principle 6 | Dialogue
  We will facilitate and support dialogue and debate among educators, students, business, government, consumers, media, civil society organizations and other interested groups and stakeholders on critical issues related to global social responsibility and sustainability.

In 1973, three lecturers, Ed Altman, Richard Zisswiller and Jim Ball formed the first international network for the exchange of business students. Thanks to the business schools: Ecole des Hautes Etudes Commerciales (HEC), New York University (NYU) and London Business School (LBS), student exchange became possible. The Partnership in International Management (PIM) is today a consortium of the best business schools from around the world that enables the exchange of students for one academic semester. The PIM network includes 65 business schools from around the world, including 22 from Europe. PIM member institutions made it possible to exchange several thousand students.

Members meet each year to network, discuss PIM development and growth strategies, share best practices, and jointly address issues that impact international education.

The International Association for Management Development in Dynamic Societies (CEEMAN) is an international association founded in 1993 with the aim of increasing quality and developing management in Central and Eastern Europe. It is a global network of institutions with 200 members from 50 countries in Europe, North America, Latin America, Africa and Asia. CEEMAN supports the quality of management development and change processes through the development of education, consulting, research, network support, information and other related services operating in transitory and dynamically changing environments.

The CEEMAN platform aims at:

- setting international quality standards in management education,
- promoting principles of responsible management education,
- supporting transitional and change processes,
- encouraging respect for diversity and culture,
- fostering innovation, creativity, and holistic approach to management development.

The European University Association (EUA) was established in 2001 as a result of the merger of the CRE European Universities Association and the Confederation of European Union Rectors' Conferences. EUA is a non-profit organization mainly funded by its members and represents over 800 universities in 48 European countries. The EUA plays an important role in the Bologna Process and influences EU policy on higher education, research and innovation. EUA enables best practice

by participating in projects and events involving multiple universities. EUA's mission is to promote the development of a coherent education and research system at European level through studies, projects and services.

EUA supports universities by:

- promoting European policies that will strengthen the role of universities in the development of European knowledge societies,
- promoting networking opportunities between national rectors' conferences, national organizations and national associations,
- increasing the visibility of European universities in the world,
- influencing key decision-makers at European, national and regional level,
- informing members about political debates affecting their development,
- developing universities' knowledge and experience through projects that involve individual institutions and bring benefits while supporting policy development,
- strengthening the governance, leadership and management of institutions through mutual learning, exchange of experiences and transfer of best practices,
- enhancing the international dimension of universities through better cooperation between their members and by establishing a dialogue with partner organizations around the world.

CESEEnet is a research information network for economists who work in the European System of Central Banks of the ESCB. CESEE deals with policy-oriented economics research, especially the economies of Central, Eastern and South--Eastern Europe. CESEEnet was established in May 2016, and is operated by the Oesterreichische Nationalbank OeNB.

The main goal is to create a virtual centre of excellence using a platform that encourages researchers from different institutions to share knowledge, exchange opinions, transfer ideas and collaborate across borders. By initiating and coordinating economic research, CESEEnet contributes to improving the quality and effectiveness of the economic policy of the ESCB.

The list of research topics includes: monetary policy, international macroeconomics, exchange rate policy, inflation, fiscal policy, labor markets, competitiveness, international trade, balance of payments, financial sector, forecasting, econometric modeling, housing, growth, institutions, and others.

The Observatory Magna Charta is a signatories' association, which is independent from political organisations and interest groups. The signatory universities, through their rectors, presidents and vice-chancellors, are associated with the organization by pledging to observe the principles of the Magna Charta Universitatum. The Observatory is committed to ensuring the integrity of intellectual and scientific work in institutions and society, in order to strengthen trust in relations between universities and their communities: local, regional, national or global. In 1986 the University of Bologna proposed the Magna Carta idea to the oldest European universities. In June 1987, during a meeting in Bologna, delegates from 80 European universities elected a council of eight: the President of the European Rectors' Conference, Rectors of

Bologna Universities, Paris I, Leuven, Barcelona, Professor Giuseppe Caputo from the University of Bologna, Professor Manuel Nunez Encabo – Chairman of the Universities Subcommittee of the Parliamentary Assembly of the Council of Europe. In January 1988, a document was drawn up in Barcelona which was signed by all the rectors who stayed in Bologna on the occasion of the 900th anniversary of Alma Mater. The purpose of this document is to respect the deepest values of university traditions, encouraging strong ties between European universities. The Magna Charta Universitatum has been signed by 904 Universities from 88 Countries from all continents.

CEMS is a strategic alliance of top business schools and international companies. The main goal of this network is to establish a global standard of excellence for a Master's in Management. CEMS offers a leading international Master's degree in management and its graduates receive the title of CEMS Master in International Management (MIM).

CEMS was founded in 1988 by four leading European schools: ESADE, HEC Paris, Bocconi University and the University of Cologne. It has 33 member schools, is present on all continents, and has 1,328 MIM students from 80 nationalities. CEMS cooperates with 70 international companies and 7 non-governmental organizations.

Common to all activities is the goal of promoting global citizenship, in particular the following values:

- the pursuit of excellence with high standards of performance and ethical conduct,
- understanding and drawing upon cultural diversity with respect and empathy,
- professional responsibility and accountability in relation to society as a whole.

European Doctoral Programmes Association in Management and Business Administration EDAMBA is an international non-profit association operating in 27 countries, comprising 70 universities. In 1991 a group of PhD directors in management from European business schools decided to launch EDAMBA, involved in promoting and establishing cooperation between doctoral programs in the field of management and business administration.

EDAMBA aims to:

- provide an information exchange network,
- create general promotion of scientific cooperation,
- help participating schools improve the quality of their doctoral programs and create an environment of excellence with a European perspective while pursuing diversity.

EDAMBA develops and ensures the highest standards in doctoral education in management and business studies by:

- providing a European and worldwide network for information exchange and discussion of ideas between PhD students, programmes and schools,
- promoting, improve and develop best practices through codes of conduct at the highest level,

- offering a global platform that enables new research initiatives and practice across borders,
- helping participants in doctoral programmes around the world to continuously improve quality and achieve excellence by building a common dialogue on diversity, social and human goals, instilling intellectual capacity, personal sensitivity, and public and moral responsibility.

The New Initiatives and Challenges in Europe, NICE is an inter-university network consisting of more than 30 partner institutions from 21 countries in the enlarged EU, Australia, Asia and the Middle East. In 1992, 12 universities from 5 EU Member States gathered at the IPAG Business School in Nice, France, to apply for ERASMUS funding. When the EU changed its project support policy in 1996, the group decided to continue cooperation by extending the network to more countries.

Network members meet annually to exchange ideas, conduct multilateral research programmes, develop collaborative projects and create partnerships for their students.

Higher education institutions collaborating within the NICE network pursue the following goals:

- increasing the internationalization of member institutions,
- facilitating the exchange of students, teaching and other staff,
- developing joint programmes and modules,
- developing dual and joint study programmes, sharing experiences – examples of good practice,
- facilitating scientific cooperation.

The Atlas Economic Research Foundation was founded in 1981 by Antony Fisher, the founder of the think tank, which connects 441 partners in 95 countries around the world. Atlas Network increases global prosperity by strengthening networks of independent partner organizations. These organizations promote individual freedom and are involved in identifying and breaking down barriers to human development. Atlas provides world-class seminars, mentoring, workshops and other learning opportunities for independent partners. It also offers contests with grants and prizes that enable development and success. It supports camaraderie and stimulates partners' ambitions through events and contacts with the media. This approach aims to strengthen the global freedom movement by expanding the global network of leaders and thinkers of think tanks to promote the idea of freedom. In its first four decades, the Atlas Network played a significant role in the work of many law enforcement organizations around the world, including the Manhattan Institute in New York, the Afghanistan Economic and Legal Studies Organization, the Acton Institute in Michigan, Fundación Libertad in Argentina, the Lithuanian Free Market Institute, Instituto Libertad y Desarrollo in Chile, the Centre for Civil Society in India, the Lebanese Institute for Market Studies, the Free Market Foundation in South Africa, CEDICE Libertad in Venezuela, the Fraser Institute in Canada, Istituto Bruno Leoni in Italy, the Advocata Institute in Sri Lanka, the Centre for Development

and Enterprises Great Lakes in Burundi, and the Association for Liberal Thinking in Turkey, among others.

3. Social network analysis – indicators of roles and positions

In the analysis the authors used data matrix NxN describing connections between universities in social networks, and analysed 150 universities of economics from all over Europe that belong to the network (at least five). Universities belonging to less than five networks were removed in the previous step of the analysis.

To describe these networks the study used 19 metrics (measures) in the social network analysis:

1. Betweenness: the extent to which a node lies between other nodes in the network. This measure takes into account the connectivity of the node's neighbours, giving a higher value for nodes which bridge clusters. The measure reflects the number of people with whom a person is connecting indirectly through their direct links.

2. Bridge: an edge is said to be a bridge if deleting it would cause its endpoints to lie in different components of a graph.

3. Centrality: this measure gives a rough indication of the social power of a node based on how well they 'connect' the network. "Betweenness", "Closeness", and "Degree" are all measures of centrality (Bonacich, 1972).

4. Centrality degree: the difference between the number of links for each node divided by the maximum possible sum of differences. A centralized network will have many of its links dispersed around one or a few nodes, while a decentralized network is one in which there is little variation between the number of links each node possesses (Freeman, 1979).

5. Closeness: the degree an individual is near all other individuals in a network (directly or indirectly). It reflects the ability to access information through the 'grapevine' of network members. Thus, closeness is the inverse of the sum of the shortest distances between each individual and every other person in the network (see also: Proxemics). The shortest path may also be known as the "geodesic distance" (Valente and Foreman, 1998).

6. Clustering coefficient: a measure of the likelihood that two associates of a node are associates themselves. A higher clustering coefficient indicates a greater 'cliquishness'.

7. Cohesion: the degree to which the actors are connected directly to each other by cohesive bonds. Groups are identified as 'cliques' if every individual is directly tied to every other individual, 'social circles' if there is less stringency of direct contact, which is imprecise, or as structurally cohesive blocks if precision is wanted (Watts, 1999).

8. Degree: the amount of the number of ties to other actors in the network, see also 'degree' (graph theory).

9. Density (individual-level): the degree a respondent's ties know one another/ proportion of ties among an individual's nominees.

10. Network or global-level density is the proportion of ties in a network relative to the total number possible (sparse versus dense networks).

11. Flow betweenness centrality: the degree that a node contributes to the sum of maximum flow between all pairs of nodes (not that node).

12. Eigenvector centrality: a measure of the importance of a node in a network. It assigns relative scores to all nodes in the network based on the principle that connections to nodes having a high score contribute more to the score of the node in question.

13. Local bridge: an edge is a local bridge if its endpoints share no common neighbours. Unlike a bridge, a local bridge is contained in a cycle.

14. Path length: the distances between pairs of nodes in the network. Average path-length is the average of these distances between all pairs of nodes.

15. Prestige: in a directed graph prestige is the term used to describe a node's centrality. "Degree Prestige", "Proximity Prestige", and "Status Prestige" are all measures of Prestige.

16. Reach: the degree any member of a network can reach other members of the network.

17. Structural cohesion: the minimum number of members who, if removed from a group, would disconnect the group.

18. Structural equivalence: refers to the extent to which nodes have a common set of linkages to other nodes in the system. The nodes do not need to have any ties to each other to be structurally equivalent.

19. Structural hole: static holes that can be strategically filled by connecting one or more links to link together other points. Linked to ideas of social capital: if you link to two people who are not linked, you can control their communication.

The network analysis conducted in R software using qgraph library gives the following network (Figure 1).

In this network the study obtained 4285 edges with 1 unique weights and 0 direct edges.

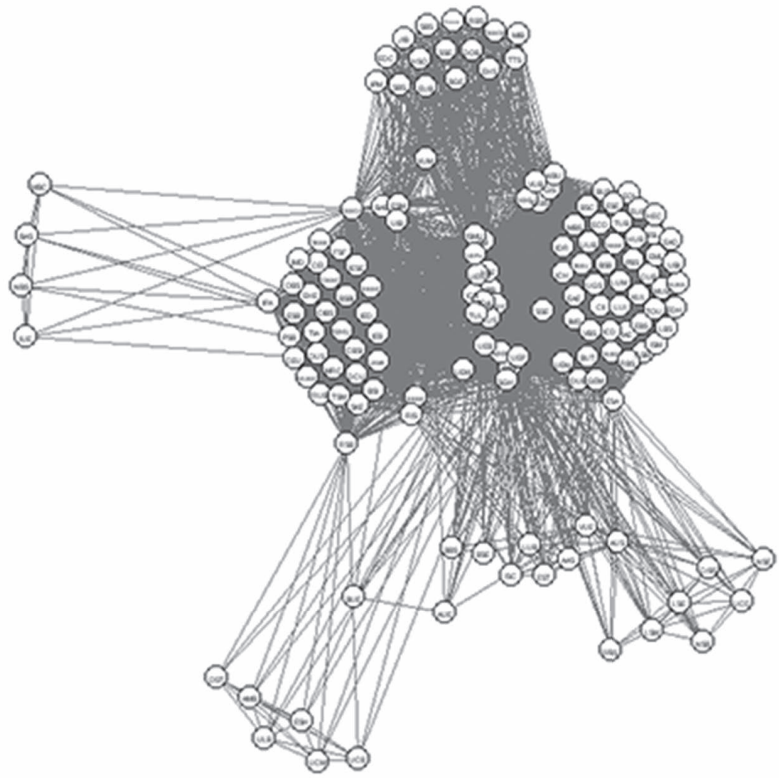

Fig. 1. Network analysis of European universities

Source: own computation using R software.

4. Visualisation of Polish universities of economics in the network structure

Four methods of visualization of network models were presented: force-directed algorithms, multivariate scaling, principal components analysis and Eigen models (Hevey, 2018; Jones 2020; Jones, Mair, and McNally, 2018).

4.1. Force-directed algorithms

Figure 1 shows the analysis based on Force-Directed Algorithms. The main advantage of this method is its visualization: the nodes in the graph rarely coincide, and the relatively equal distance between the nodes allows one to easily see the edges. The downside to this method is that the spacing between the nodes cannot be interpreted (Epskamp et al., 2012).

4.2. Multidimensional scaling

Let $\boldsymbol{R} = [r_{ij}]_{nxn}$ be an correlation matrix and $\Delta = [\delta_{ij}]_{nxn}$ be a dissimilarity matrix where $\delta_{ij} = \sqrt{1 - r_{ij}}$. MDS scales n objects to space dimension *p*, that is, it is determined by the configuration matrix *X* with dimension $n \times p$:

$$d_{ij}(\boldsymbol{X}) = \sqrt{\sum_{s=1}^{p} (x_{is} - x_{js})^2}$$

with $d_{ij}(\boldsymbol{X})$ as the fitted distances, which can be achieved by minimizing the stress target function:

$$\sigma(\boldsymbol{X}) = \sum_{i<j} (\hat{d}_{ij} - d_{ij}(\boldsymbol{X}))^2 \rightarrow \text{min!}$$

$\hat{d}_{ij} = f(\delta_{ij})$ is a transformed version of the input dissimilarities. Most popular transformation functions $f(\cdot)$ used in MDS are a linear transformation (interval MDS or ratio MDS), or a monotone step function (ordinal MDS otherwise nonmetric MDS). The transformed dissimilarities $\hat{d}_{ij}$ are called disparities or dhats. The most popular normalizations of the raw stress $\sigma(X)$ is the stress-1:

$$\sigma_1(\boldsymbol{X}) = \sqrt{\frac{\sigma(\boldsymbol{X})}{\sum_{i<j} \hat{d}_{ij}^2}}.$$

For two MDS solutions with configuration matrices *X* and *Y* (dimensions $n \times p$), they can be aligned using Procrustes. This procedure removes statistically 'meaningless' differences (which do not change the fit of solution) between the two Multidimensional Scaling configurations. These transformations are rotation, dilation, and translation.

Let X be the target configuration and Y the tested configuration to be transformed, and *Z* – a centering matrix: $\boldsymbol{Z} = \boldsymbol{I} - n^{-1}11'$. Procrustes is carried out in three steps:

compute $\boldsymbol{C} = \boldsymbol{X'ZY}$
Singular Value Decomposition on C: $\boldsymbol{C} = \boldsymbol{P}\Phi\boldsymbol{Q'}$
rotation matrix $\boldsymbol{T} = \boldsymbol{QP'}$
dilation factor $s = tr(\boldsymbol{X'ZYT})/tr(\boldsymbol{Y'ZY})$
translation vector $\boldsymbol{t} = n^{-1}(\boldsymbol{X} - s\boldsymbol{YT'})\boldsymbol{1}$
solution $\widehat{\boldsymbol{Y}} = s\boldsymbol{YT} + \boldsymbol{1t'}$.

Unlike Force-Directed Algorithms, in Multidimensional Scaling the distances between nodes can be interpreted, i.e. nodes that are close to each other are more closely related, and nodes that are further apart are less related. The stress value

provides an estimate of how distances are interpretable, a low stress value means the distances are highly interpretable; high stress value mean the distances are not very interpretable, which is why the network is large. A disadvantage of MDS is that nodes can be placed very close to each other, making the edges more difficult to see.

The MDS network analysis conducted in R software using networktools (function MDSnet) library gives the following network (Figure 2).

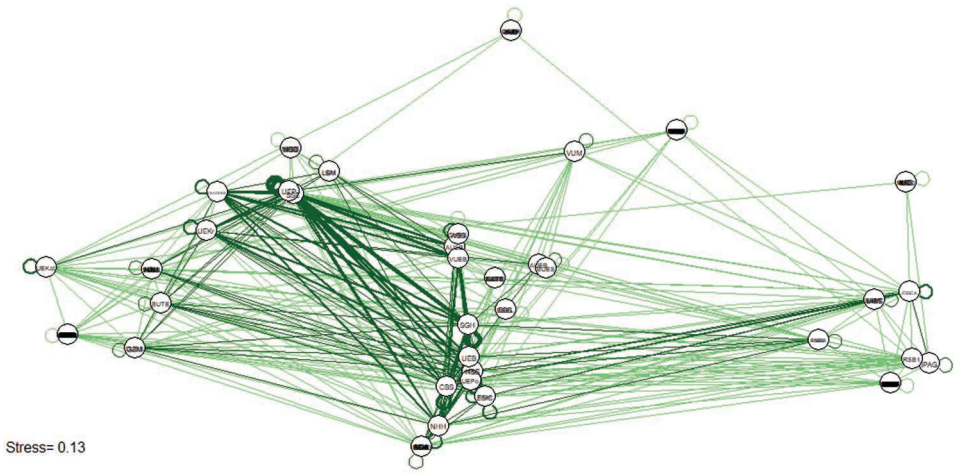

Fig. 2. MDS network analysis of European universities

Source: own computation using R software.

In the model shown in Figure 2 the stress value is small, which means the distances are highly interpretable. The nearest to the centre of the network is the SGH, which is most closely connected with UE Wrocław and UE Poznań. These universities cooperate with universities from Slovakia, Denmark, Norway, Spain, Austria, Finland, Romania and Greece. On the other hand, UE Kraków cooperates more closely with UE Katowice. These universities have established closer cooperation with universities from Hungary, Spain, Sweden, the Czech Republic and Belgium.

4.3. Principal component analysis

PCA is a procedure that transforms a set of correlated variables into a set of new orthogonal variables, called principal components. This method is often used for dimension reduction. In PCA the first extracted principal component contains the largest amount of variance, and each subsequent component contains less variance than the last. PCA is especially useful when much of the variance in the data can be included in just a few principal components, which helps with interpretation or visualization (Chan et al., 2015).

Let X be the column-centred of the data matrix dimension $n \times m$, divided by $\sqrt{n-1}$. An SVD decomposes X into the following three matrix:

$$\boldsymbol{X = UDV'}.$$

U is a matrix dimension $n \times m$, which contains the left singular vectors, V is an $m \times m$ matrix, which contains the right singular vectors. D is a diagonal matrix dimension $m \times m$ with the singular values on the diagonal. The singular values reflect the standard deviations of the main components by which one can calculate the proportion of variance explained by the subsequent components. The U matrix contains the loadings of the principal components, and the principal components scores can be obtained using $\boldsymbol{UD}\sqrt{n-1}$. PCA can also be calculated using Eigenvalue decomposition.

The advantage of this method is that the arrangement of the nodes in the XY plane becomes interpretable, i.e. the nodes on the right side differ from the nodes on the left. The two-component percentage of variance shows how the node positions are interpretable. PCA is based on a correlation matrix or set of observational variables. Thus, the main component analysis has the disadvantage that it specifically applies to networks based on correlation matrices (psychometric networks), but not to directly derived networks (e.g. social networks). Like MDS in PCA, edges can be difficult to see if the nodes have very similar values in both components.

The PCA network analysis conducted in R software using networktools (function PCAnet) library gives the following network (Figure 3).

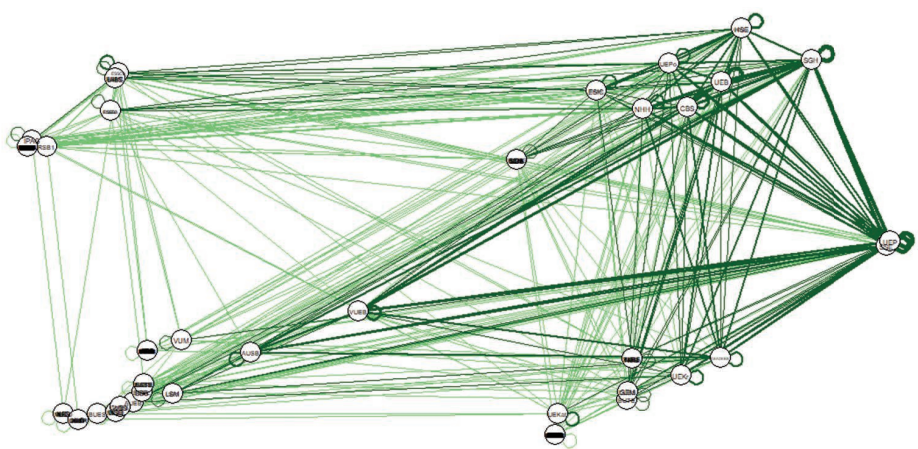

Fig. 3. PCA network analysis of European universities

Source: own computation using R software.

SGH is the Polish university with the most connections in this network, it is the closest to the UE Wrocław and UE Poznań. These universities cooperate with universities from Slovakia, Denmark, Norway, Spain and Finland. On the other

hand, UE Kraków cooperates more closely with UE Katowice. These universities establish closer cooperation with universities from Hungary and Spain.

4.4. Eigen models

The data to be considered in an Eigen model consist adjacency matrix $\boldsymbol{Y} = [Y_{ij}]_{nxn}$ (e.g. a correlation matrix). Y_{ij} is defined as a function of latent variables $\boldsymbol{u}_i$ and $\boldsymbol{u}_j$ or a regression model with adjacency predictor vector $\boldsymbol{x}_i$. The number of dimensions p is to be fixed a priori.

$$Y_{ij} = f(\boldsymbol{\beta}'\boldsymbol{x}_{ij} + \boldsymbol{u}_i\boldsymbol{\Lambda}\boldsymbol{u}_j).$$

This Eigen-model approach uses the Markov chain Monte Carlo. Without considering predictors to give the matrix $\widehat{\boldsymbol{\Lambda}}$ (dimension $p \times p$) this gives the relative importance of each dimension, and the matrix $\widehat{\boldsymbol{U}}$ (dimension $n \times p$). In $\widehat{\boldsymbol{U}}$ each node i gets a row vector $\widehat{\boldsymbol{u}}_i = (\hat{u}_{i1}, \hat{u}_{i2}, \ldots, \hat{u}_{ip})$ containing the unobserved node characteristics. Similar $\widehat{\boldsymbol{u}}$-vectors will get nodes with similar characteristics. The vectors $\widehat{\boldsymbol{u}}_i$ are not orthogonal. Apply an Eigenvalue decomposition on the fitted matrix $\widehat{\boldsymbol{U}}\widehat{\boldsymbol{\Lambda}}\widehat{\boldsymbol{U}}'$. The resulting Eigenvectors reflect the coordinates in the p-dimensional space, these can be subject to plotting.

Eigen models are similar to PCA in terms of plotting and interpreting the networks. The arrangement of nodes on the XY plane can be interpreted in terms of hidden dimensions of the network. The advantage of Eigen models over PCA is that they are calculated from any network structure and not based on a correlation matrix.

The Eigen-models network analysis conducted in R software using networktools (function EIGENnet) library gives the following network (Figure 4).

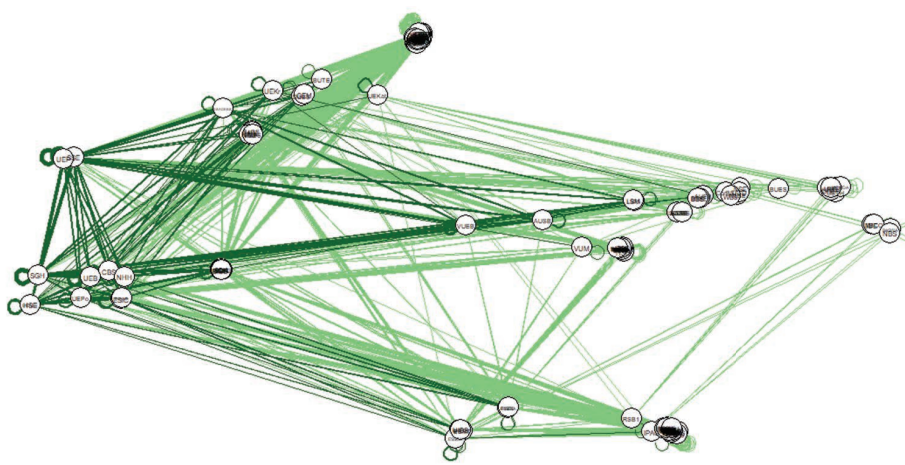

Fig. 4. Eigen-models network analysis of European universities

Source: own computation using R software.

The Eigen-model method gives a similar interpretation to the MDS. SGH, UE Wrocław and UE Poznań cooperate with universities from Slovakia, Denmark, Norway, Spain, Austria, Finland, Romania and Greece. On the other hand, UE Kraków and UE Katowice establish closer cooperation with universities from Hungary, Spain, Sweden, the Czech Republic and Belgium.

5. Conclusions

The article identified the network system of Polish universities of economics among their European counterparts belonging to the same networks and indicated the positions of Polish universities within these networks. Specific research questions answered in the article were as follows:

1. What is the overall structure of the universities of economics network?
2. Which universities Take central and peripheral positions in the network?
3. What is the structure of the ego-networks of Polish universities of economics?
4. What is the spatial interconnectedness of Polish universities of economics?
5. What are the differences between the network visualizations across the methods used?

The presented paper shows different methods that allowed for the identification of network systems of Polish universities of economics in the European universities. SGH, UE Wrocław and UE Poznań cooperate most closely with: Slovakia, Denmark, Norway, Spain, Finland, Sweden and the Czech Republic. On the other hand, UE Kraków and UE Katowice cooperate most closely with: Hungary, Spain, France, Estonia, Sweden and the Czech Republic.

Based on the four presented models, it can be noted that the universities: SGH, UE Wrocław and UE Poznań are more related to each other than to UE Kraków and UE Katowice. The first three universities (SGH, UE Wrocław, UE Poznań) cooperate most closely with: UEB (Slovakia), CBS (Denmark), NHH (Norway), ESIC (Spain), HSE (Finland) and SSE (Sweden), UEP (the Czech Republic). On the other hand, UE Kraków and UE Katowice cooperate most closely with: BUTE (Hungary), ESADEBS (Spain), GEM (France), EsBS (Estonia) and SSE (Sweden), UEP (the Czech Republic).

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POLSKIE UNIWERSYTETY EKONOMICZNE W SIECIACH EUROPEJSKICH

Streszczenie: Ostatnio dużym problemem stała się ocena badań prowadzonych na europejskich uczelniach. Troska o jakość i ocenę badań naukowych prowadzonych na uczelniach zwiększa znaczenie rankingów uczelni, zwłaszcza rankingów światowych. W artykule zastosowano podejście sieciowe do analizy powiązań europejskich uniwersytetów korzystających z sieci uniwersytetów. Sieci umożliwiają wizualizację złożonych, wielowymiarowych danych i zapewniają wskaźniki statystyczne do interpretacji wynikowych wykresów. Analiza obejmuje 150 uczelni ekonomicznych w Europie i 11 sieci uniwersytetów. Analizy sieciowe wykonano programem R. W artykule przedstawiono różne metody, które pozwoliły na identyfikację systemów sieciowych polskich uczelni ekonomicznych na uczelniach europejskich, oraz sieci społecznościowych na podstawie wskaźników sieciowych.

Słowa kluczowe: analiza czynnikowa (PCA), skalowanie wielowymiarowe (MDS), analiza sieci, uniwersytety ekonomiczne.