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Dynamic Cluster Analysis of Educated and Smart Society Development in European Union Countries

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Abstract:

Purpose: *The aim of the paper is to analyze the educational and smart society development process in the European Union countries, in 2003-2017.*
Design/Methodology/Approach: *17 variables have been used for the multivariate analysis of the problem. Multiple regression was the main method for missing data imputation. The number of clusters was identified in dendrogram of Ward's agglomerative clustering method, and final partition obtained by k-means method. Composite Index of Educational and Smart Development has been proposed to measure the general level of each cluster.*
Findings: *Five cluster have been identified and characterized. Their dynamic geographical composition changed over time with a tendency for many countries to move toward higher level clusters.*
Practical Implications: *It seems that educational part of Europe 2020 Strategy works rather well for most of the EU countries*
Originality/Value: *The choice of variables is always somehow subjective. Dynamic cluster analysis seems to be promising approach in identifying changes in both level and structure. The new measure for cluster stability has been proposed in the paper.*

Keywords: *Smart development, European Union, cluster analysis, composite index, cluster stability.*

JEL codes: *C38, I21, O52, O57.*

Paper type: *Research study*

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1. Introduction

"Smart" is a very popular word nowadays, connected with many objects such as cities, buildings, cars, etc. The most general is a society. Haupt (2017) cites different definition and opinions on smart development. We follow the one by Charles Leadbeater, author, and opinion leader "*A smart society is one that generates and uses knowledge to be more successful"*. We considered education, R&D expenditures, innovations, and information technology as main pillars of society development. Smart and sustainable development which improves social inclusion is an important challenge for EU (Europe, 2020). It is difficult to measure directly such a multidimensional phenomenon as social development, so the multivariate techniques of analysis should be applied. The aim of the paper is to analyze the development process in EU countries, in terms of educational and smart society issues.

2. Literature Review

Education, investment in knowledge, skills and competences, human capital and their importance for individual people, enterprise, and economy as a whole – are important subject in scientific literature. Due to the huge capacity of publications, only ideas presented by most important economists, such as Smith, Schultz, Becker and Sen, are briefly presented here. The importance of qualification was described by economists when the power of mind was recognized, as can be seen in some mercantilists, such as Mun (1571-1641) (Britanica, 2017).

Adam Smith was one of the first economists who pointed out that the human being can be treated also as the form of capital. In his famous publication from 1776, *"An Inquiry into the Nature and Causes of the Wealth of Nations"* he underlined the importance of skills acquired during education, being the wealth both for individual and the society. The differences in work performance by those with different education levels and experience should be reflected in their wages and most talented should have suitable benefits (Smith, 2007).

Nobel Prize Winner T.W. Schultz in *"Investment in Human Capital"* (Schultz, 1961) wrote that human capital is "embodied in humans". Higher benefits for economy can be achieved by investing in humans, through education (basic and continuous), rather than in material capital. Each person has an innate abilities and knowledge, which can be developed. This development in realized by schooling, new qualifications and experiences gained during professional career, good health conditions. The individual's development is an important factor for the wealth of a nation (Schultz, 1976).

Another Nobel Prize Winner G. Becker in *"Investment in human capital: A theoretical analysis"* (Becker, 1962) and in *"Human Capital"* (Becker, 1993) – based on A. Smith's ideas – developed the concept of human capital investment, i.e., resource allocation for future income. He underlined the importance of school

education, new qualifications, professional experience, and knowledge of economy in development of human abilities. Knowledge, science, and technology are important factors of economic development (Becker, 1962).

Considerations on education and its importance for humans and economy are present in many books and papers by Sen (1993; 1994; 1999; 2002). Unterhalter (2003a) summarized Sen's idea that education can be recognized as:

- form of well-being achievement and functioning, realized by schooling (e.g., completing four grades of primary school),
- part of a realization of abilities for exercising agency, reflection, search for information, understanding and recognizing the privilege to use these skills for everyday activities and conduct.

Sen wrote that the education level in organizations is based on the ability to secure conditions important for functioning and task fulfilment. Education (also forced by basic schooling obligation) gives freedom and helps in orientation towards future (Saito, 2003).

In classical economy, the importance of knowledge and skills for the society is widely recognized. It is an important factor for wealth development of the country and its supremacy. Compulsory education in not only the case for individuals, but also for the country, and skills and abilities are part of the society wealth (Czajka, 2011; Dacko-Pikiewicz and Walancik, 2016; Rodionova *et al.,* 2018; Shimada, 2018; Stuss *et al.,* 2019). Two groups of approaches can be distinguished in the history of economic thoughts:

1. Treating humans as capital, whose value can be measured – introduced by W. Petty, then continued by vulgar economists: W.N. Senior, H.D. Macleod, J.R. McCulloch, and subjectivists as L. Walras, V. Pareto, J.S. Nicholason and J.H. von Thunen (Kunasz, 2004).
2. Separately treating human being and capital carried by him – skills, knowledge, abilities, energy, and health cumulated by certain investments. Human capital can be assigned to material capital (A. Smith, J.R. Walsh, G.S. Becker, T.W. Schultz or to the non-material capital (J.B. Say, F. List) (Domański, 1993).

3. Data

Selection of variables to characterize educated and smart society development was based on literature review and availability of EU countries complete covering relative long-time span. Data has been collected from the web page of the Central Statistical Office Poland. It has been chosen from the STRATEG data base covering smart development and cohesion policy (Strateg, 2020). We took the following variables:
X_1 – Expenditures on R&D as % in GDP,
X_2 – % of population using internet at least once a week,

X_3 – Number of inventions reported to EPO for million population,
X_4 – PISA (Programme for International Student Assessment) test – % of students on high levels in reading and interpretation,
X_5 – HDI (Human Development Index),
X_6 – PISA test – % of students on the high levels in mathematics,
X_7 – PISA test – % of students on high levels in science,
X_8 – Government and higher education sector expenditures on R&D in % of GDP,
X_9 – Corporate expenditures on R&D in % of GDP,
X_{10} – % of small and medium enterprises adopting product or process innovations,
X_{11} – % of population with high internet skills,
X_{12} – % of employers working in R&D,
X_{13} – % of young people not working or learning,
X_{14} – % of teenagers who quit education,
X_{15} – % of 25-64 population active in life-long learning,
X_{16} – % of 30-34 population with higher education,
X_{17} – % of population with basic or higher computer skills.

For multidimensional analysis the complete data matrix is needed. More than half of variables had missing data cells, some of the variables have been measured only every second year. We applied regression analysis (using complete variables as independent ones) as the main tool for data imputation. If only three values were available for 15-year period, arithmetic average substituted missing values.

Most of the variables used in analysis were stimulants (the bigger the better), and the only variables which were destimulants (variables 13 and 14) relate to the number of youngsters early quitting education. Stimulants – except the number of patents per million population (X_3) and HDI (X_5) – have been calculated as percentage shares, with natural limits 0 and 100.

4. Method

Our data cube consists of 28 countries x 17 variables x 15 years. Dynamic cluster analysis (Markowska, 2012) was the main method used to analyze the level, homogeneity, geographical distribution, and changes in education and smart development of EU countries. According to the scheme by (Sokołowski, 1982) our task can be defined as [YT, Z], which is a spatio-temporal analysis. Each country in each year is treated as an individual object (operational taxonomic unit). Data cube was transformed into data matrix with 420 rows (28 countries x 17 years) and 17 columns (variables). Ward's agglomerative method was used to decide the number of clusters and final partition was obtained by k-means method. Then we study the composition of clusters and their changes over time. Each cluster was characterized by within-cluster means of variables (also tested by ANOVA) and a composite indicator summarizing the human smart development. Composite Index of Education and Smart Development (W) is defined by (1), for each country, for each year.

$$W_{it} = \frac{100}{m}\sum_{j=1}^{m} x_{itj}^{*} \quad (1)$$

where $x_{itj}^{*} = \frac{x_{itj} - \min_{j}\{x_{itj}\}}{\max_{j}\{x_{itj}\} - \min_{j}\{x_{itj}\}}$ for stimulants (the bigger the better)

and $x_{itj}^{*} = \frac{\max_{j}\{x_{itj}\} - x_{itj}}{\max_{j}\{x_{itj}\} - \min_{j}\{x_{itj}\}}$ for destimulants (the smaller the better)

where: *i* – object number (there are *n* objects in total), *j* – variable number, *m* – number of variables, *t* – time unit (year).

There are (*n* x *t*) spatio-temporal operational taxonomic units.

Finally, we assessed cluster stability by coefficient CS (2).

$$CS = \frac{S-n}{n(T-1)} \quad (2)$$

where: S is the sum of elements in the membership matrix (presented in Tables 3-6), n – number of countries in the cluster and
T is the number of years in the analyzed period.

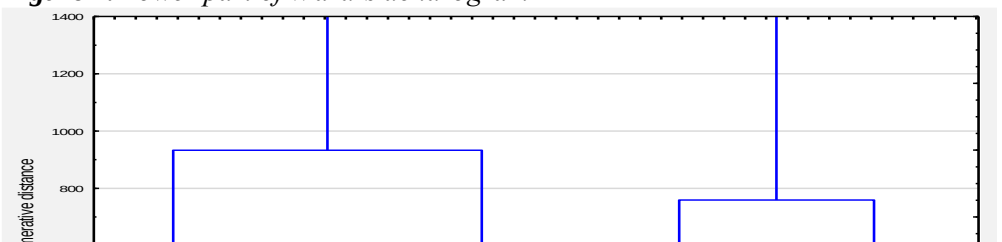
CS takes values from [0;1] interval. It assumes zero when each country is present in the cluster only in one year, and value of one if the composition of cluster is the same throughout the whole period.

5. Results

Ward's agglomerative algorithm (with squared Euclidean distance as a distance measure) produced a dendrogram presented as Figure 1. We used the criterion of "the first big increase in the agglomerative distance" which suggested 5 clusters (Figure 2). As mentioned, the final partition was obtained by k-means method, and clusters were arranged according to the diminishing average of Composite Indicator W. Groups were characterized by mean values of variables (Table 1). Differences between them have been tested by one-way ANOVA, and for all variables they were statistically significant.

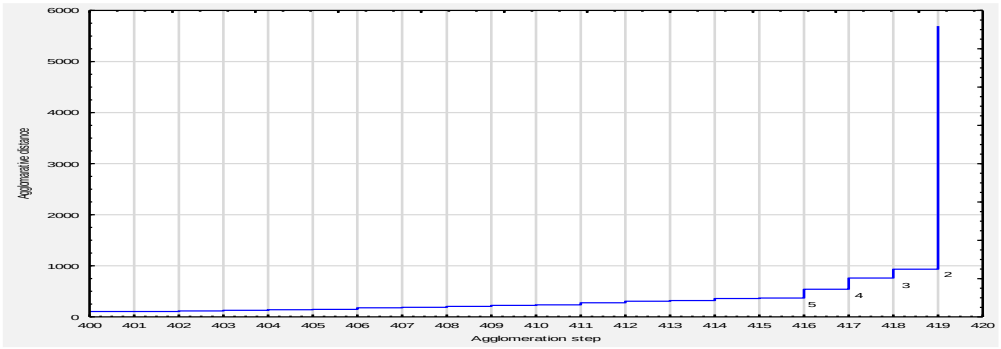
To ease the interpretation, the above values have been classified into three levels: high, low, and medium (Table 2). For each variable, mean values were ordered, and two biggest differences in consecutive values defined the borders between three classes.

Figure 1. *Lower part of Ward's dendrogram*



Source: *Own calculation.*

Figure 2. *Agglomeration process*



Source: *Own calculation.*

Table 1*. Arithmetic averages in clusters*

Cluster	Expen. on R&D	Internet usage	Inventions	PISA reading	HDI	PISA maths	PISA science	Governm. exp. R&D	Corporate exp. R&D
A	2.96	82.94	252.66	9.69	0.91	14.39	10.73	0.92	2.03
B	1.86	68.18	120.64	8.53	0.88	14.39	10.01	0.65	1.20
C	1.34	59.13	72.52	10.31	0.91	10.32	8.66	0.42	0.92
D	0.93	61.79	17.49	5.14	0.84	8.89	5.10	0.48	0.42
E	0.68	34.06	13.35	3.74	0.81	5.97	3.56	0.37	0.28
Cluster	Innovati o.	High internet skills	Employment in R&D	Young not working	Teenagers quitting education	Life-long learning	High educ.	Basic computer skills	W
A	40.99	14.42	2.78	9.32	8.95	21.23	41.42	69.22	69
B	36.65	10.94	2.01	12.29	10.26	12.45	37.45	58.18	54
C	43.39	4.93	1.77	17.11	10.17	7.12	48.23	42.27	48
D	25.27	14.21	1.46	18.36	10.89	5.93	33.43	48.00	37
E	24.73	5.09	0.99	18.18	18,53	4.31	24.07	42.69	28

Source: *Own calculations.*

Table 2*. Arithmetic averages levels in clusters*

Cluster	Expen. on R&D	Internet usage	Inventions	PISA reading	HDI	PISA maths	PISA science	Governm. exp. R&D	Corporate exp. R&D
A	High	High	High	High	High	High	High	High	High

B	Medium	Medium	Medium	High	High	High	High	Medium	Medium
C	Low	Medium	Medium	High	High	Medium	High	Low	Medium
D	Low	Medium	Low	Medium	Medium	Medium	Medium	Low	Low
E	Low	Low	Low	Low	Low	Low	Low	Low	Low
Cluster	Innovatio.	High internet skills	Employment in R&D	Young not working	Teenagers quitting education	Life-long learning	Higher educ.	Basic computer skills	W
A	High	High	High	Low	Low	High	Medium	High	High
B	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium	Medium
C	High	Low	Medium	High	Medium	Low	High	Low	Medium
D	Low	High	Medium	High	Medium	Low	Medium	Low	Low
E	Low	Low	Low	High	High	Low	Low	Low	Low

Source: *Own calculations.*

Group A ($\overline{W}$=69; CS=0,633)

This group is characterized by the highest values of total, governmental and corporate expenditures on R&D, regular internet usage and high internet skills, inventions (more than two times higher than in the next group), HDI, PISA results in mathematics and science, employment in and R&D, and at least basic computer skills. Not surprisingly the lowest percentage of youngsters in countries in this group quit education and do not go to work (Table 3).

Table 3. *Spatio-temporal structure of cluster A*

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Belgium	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Denmark	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Germany	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Netherlands	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Austria	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Finland	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Sweden	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: *Own calculations*.

Scandinavian countries Denmark, Finland and Sweden are in this best group since 2003. In 2009 and 210 they were joined by Germany, Netherlands, and Austria.

Group B ($\overline{W}$=54; CS=0,682)

The second group is characterized by the highest PISA results in mathematics (together with Group A). Other PISA results are also in high class, as well as HDI. All the other variables are in medium level. Four countries were in this class during the whole period: France, Netherlands, Slovenia, and United Kingdom, and they were joined by Estonia in 2006 and Czechia in 2012. Belgium left for cluster A just on the last year of analysis (Table 4).

Table 4. *Spatio-temporal structure of cluster B*

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Belgium	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Czechia	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1
Germany	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Estonia	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
France	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Luxembourg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Netherlands	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Austria	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Slovenia	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
UK	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Source: *Own calculations.*

Group C ($\overline{W}$=48; CS=1,000)

Cluster C consist of just one country – Ireland in 2003-2017. One of the interesting features of this country is relatively large variability between variables. Six of them are in class high, six in medium and five in low. Ireland has the highest (in all means in groups) PISA results in reading and interpretation, HDI, percentage of small and medium enterprises adopting product or process innovations and percentage of 30-34 population with higher education, but the lowest values in percentages of population with high internet skills and at least basic computer skills.

Group D ($\overline{W}$=37; CS=0,500)

In terms of Composite Indicator, two groups were classified as low: D and E. None of the means characterizing group D is better than the best in other groups. It has the highest percentage of young people not working nor learning. Maybe they just sit on the web, because the only stimulant variable classified into high level is percentage of population with high internet skills (Table 5).

This group was born in fact between 2008-2010. We have here post-communist countries together with Mediterranean ones. Czechia and Estonia left for better groups and Bulgaria is just a new arrival.

Group E ($\overline{W}$=28; CS=0,439)

This group has arithmetic means of 14 out of 17 variables worse than all the other groups, and of course the lowest average value of Composite Indicator of Education and Smart Development (Table 6). The assignment of EU countries to groups is illustrated on Figure 3. Group E (with the worst averages in most variables, and the lowest average of Composite Index of Education and Smart Development), which was located in south and eastern EU in the beginning of the analysed period, slowly disappears in favour of group D.

Table 5. *Spatio-temporal structure of cluster D*

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Bulgaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
Czechia	1	1	1	0	1	1	1	1	1	0	0	0	0	0	0
Estonia	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Greece	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Spain	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Croatia	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Italy	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1
Cyprus	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Latvia	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
Lithuania	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Hungary	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
Malta	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Poland	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1
Portugal	0	0	0	0	0	0	0	0	1	1	1	1	0	1	1
Slovakia	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1

Source: *Own calculations.*

Table 6. *Spatio-temporal structure of cluster E*

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Bulgaria	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0
Greece	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Spain	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Croatia	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Italy	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0
Cyprus	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Latvia	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Lithuania	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Malta	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Poland	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Portugal	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
Romania	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Slovakia	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0

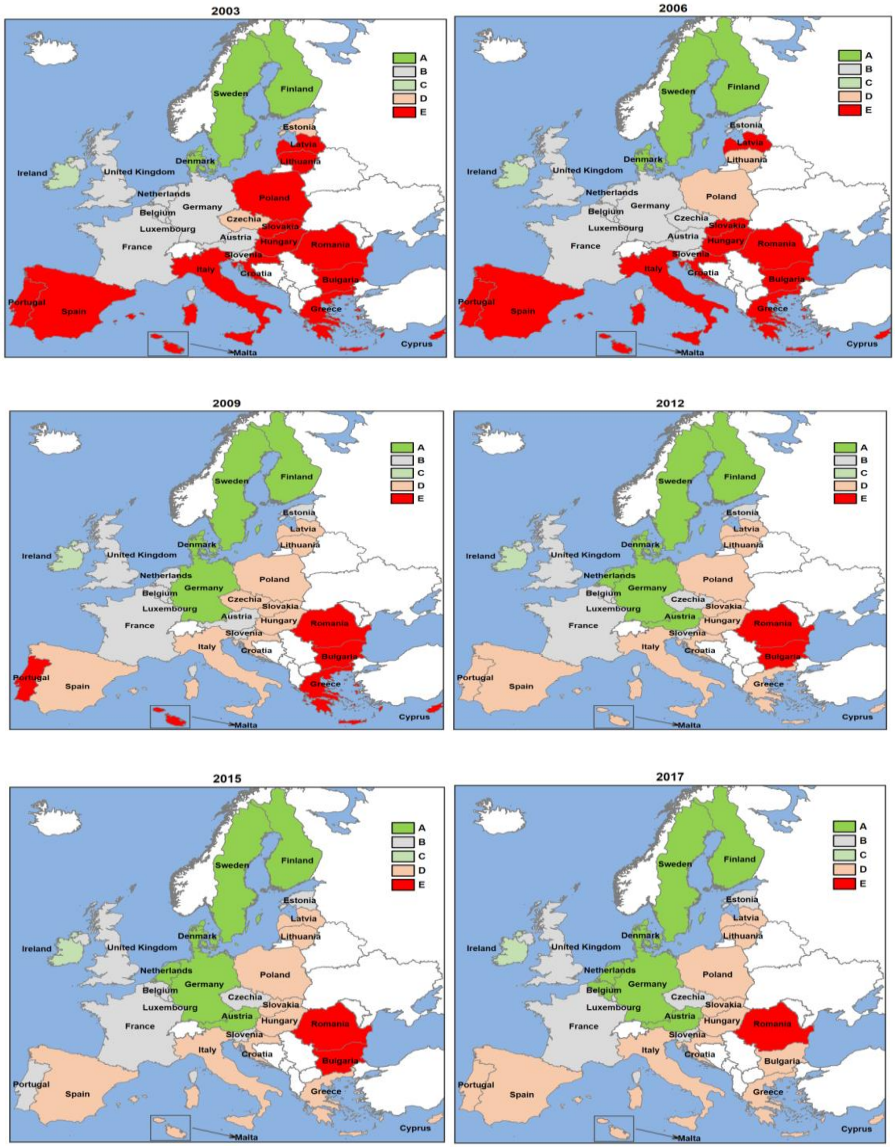
Source: *Own calculations.*

The other positive fact is the growth of group A with Scandinavian and central European countries. Group A has the best averages in most of the variables, except % of students on high levels in reading and interpretation, % of SMEs adopting innovations, and % of 30-34 population with higher education.

Maps are given in every third year (except the last one 2017), for easy evaluation of changes. In 2003 the worst level in Educated and Smart Society was observed in post-communist countries, together with south-European, Mediterranean Greece, Italy,

Spain, and Portugal. Also in 2003, the highest degrees of spatial continuity were observed – Scandinavian countries together, and so-called "old EU". Biggest part of group E (red colour), slowly moved toward group D (with only Romania left in this group in 2017), and part of "old EU" joined Scandinavian countries in the best group A. The originality of Ireland which alone formed single-country cluster is a good subject for further studies.

Figure 3. *The composition of dynamic clusters of countries in selected years*



Sources: *Own composition.*

The summary of countries' movement between classes is provided in Table 7.

Table 7. *Countries movement between clusters*

Country	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Denmark	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Finland	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Sweden	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A
Germany	B	B	B	B	B	B	A	A	A	A	A	A	A	A	A
Netherlands	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A
Austria	B	B	B	B	B	B	B	B	A	A	A	A	A	A	A
Belgium	B	B	B	B	B	B	B	B	B	B	B	B	B	B	A
Slovenia	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
UK	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
France	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Luxembourg	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Estonia	D	D	D	B	B	B	B	B	B	B	B	B	B	B	B
Czechia	D	D	D	B	D	D	D	D	D	B	B	B	B	B	B
Ireland	C	C	C	C	C	C	C	C	C	C	C	C	C	C	C
Lithuania	E	E	E	D	D	D	D	D	D	D	D	D	D	D	D
Poland	E	E	E	D	D	D	D	D	D	D	D	D	D	D	D
Latvia	E	E	E	E	E	D	D	D	D	D	D	D	D	D	D
Hungary	E	E	E	E	E	D	D	D	D	D	D	D	D	D	D
Slovakia	E	E	E	E	E	D	D	D	D	D	D	D	D	D	D
Spain	E	E	E	E	E	E	D	D	D	D	D	D	D	D	D
Croatia	E	E	E	E	E	E	D	D	D	D	D	D	D	D	D
Italy	E	E	E	E	E	E	D	D	D	D	D	D	D	D	D
Portugal	E	E	E	E	E	E	E	E	D	D	D	D	B	D	D
Greece	E	E	E	E	E	E	E	E	D	D	D	D	D	D	D
Cyprus	E	E	E	E	E	E	E	E	D	D	D	D	D	D	D
Malta	E	E	E	E	E	E	E	E	D	D	D	D	D	D	D
Bulgaria	E	E	E	E	E	E	E	E	E	E	E	E	E	E	D
Romania	E	E	E	E	E	E	E	E	E	E	E	E	E	E	E

Source: *Own calculations.*

Generally, the improvement in education and smart development is observed. Countries are moving from worse towards better classes and this process is quite stable. One-year presence of Czechia and Portugal in cluster B should be considered as random disturbance.

6. Conclusions

Multidimensional analyses were used to study changes in educated and smart society level, in EU countries. Dynamic cluster analysis based on 17 diagnostic variables allowed to identify groups of countries with homogeneous patterns of changes.

Dynamic cluster analysis provided interesting picture of geographical changes in education and smart development within European Union countries. We propose to consider the first cluster as high, the next two as medium and the last two as low. This should be treated relatively, e.g., high level is high in comparison to other clusters. All countries improve their situation in human smart development, moving towards better classes. The biggest change in class composition was observed between 2010 and 2011. Relatively, two lowest clusters D and E were the less stable. The newly proposed measure of cluster stability evaluates the degree of changes over time in the composition of obtained clusters.

The diminishing volume of groups B and E, together with growing size of groups A and D leads to some further questions. Are these changes correlated with GDP growth and the development of digital society? Are there any connections between the realization of Europe 2020 Strategy and Educated and Smart Society development level? These questions show the possible directions of further studies in the domain of mentioned spheres, within EU countries.

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