ИННОВАЦИИ И ЦИФРОВАЯ ЭКОНОМИКА

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Comparative Analysis of the Development of the Digital Economy in Russia and EU Measured with DEA and Using Dimensions of DESI

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The aim of this paper is to compare the development of the digital economy in Russia with that of the 28 countries of European Union (EU). Data were compiled from the European Commission's International Digital Economy and Society Index (I-DESI 2018) database. After providing a brief overview of various alternative ways to measure the impact of information and communications technologies (ICT), we examine the most important features, advantages, and drawbacks of this database. We then describe the structure of our dataset and proceed with the analysis of the digital competitiveness of Russia and the EU-28. Our main research questions are concerned with the robustness of the EU data supply and the stability of its ranking. For this, we use the data envelopment analysis (DEA) method and the one-dimensional version of multidimensional scaling, which can also be employed for ranking issues. In addition to the conventional DEA method, we also investigate the viability of common-weights DEA models. We compare the results obtained to answer our questions. In evaluating the results, we also discern how data from Russia matches EU data on the digital economy. The comparison suggests that methods used in our study provide a similar solution, but the ranking of a few countries (including Russia) show wider variation.

Keywords: DESI index, digital public administration, innovation, data envelopment analysis, multidimensional scaling, ranking.

Introduction

The International Digital Economy and Society Index (I-DESI) was designed to provide "an overall assessment of where the EU stands, compared to non-EU economies, in its progress towards a digital society and economy"[1]. First published in 2016, it aims to "mirror and extend" the results of the European Commission's original (EU-only) Digital Economy and Society Index (DESI) by "finding indicators that measure similar variables for non-EU countries", including Russia. Both of these are composite indices that combine several individual indicators and use similar (but not identical) weighting systems to rank each country based on its digital performance with the aim to benchmarking the development of the digital economy and society. They measure performance in five principal dimensions or policy areas: connectivity, human capital (digital skills), use of Internet by citizens, integration of technology and digital public services.

The aim of this article is to compare the development of the digital economyof Russia with the 28 countries of European Union (EU). Data were compiled from the 2018 edition of the International Digital Economy and Society Index (I-DESI 2018) database[2]. We investigatethe robustness of the EU data supply, and the stability of its ranking. For this, we used the data envelopment analysis (DEA) method and the one-dimensional version of multidimensional scaling, which can also be used for ranking. We compare the results obtained to answer our questions. In evaluating the results, we can also find out whether Russia faresbetter or worsethan the EU in the digital economy.

The paper is organized as follows. In the second part, the measurement method of DESI data is supplied with the five dimensions of the scales. The next chapter presents the ranking of the countries involved in the examinations with the five dimensions. We outline six models for ranking. First, the countries involved in the study are sorted by a weighting method known as the scoring model. The resulting index is the DESI overall index. The following two models are closely related, as we use the classic data envelopment analysis model in both of them. However, we use two slightly different databases. The reason for this is that the input criteria in our case have the best values, but in the DEA model they have to be sorted for the worst values. This sorting can be achieved in two ways: either the reciprocal of the input data is taken, or our initial data is placed on a new scale with a linear transformation. Both approaches are followed and their results are compared in this article. A disadvantage of the basic DEA model is that we need to solve a linear programming problem for as many objects as we have in our dataset (29 in our case). In the next two models, while maintaining the assumption on inputs, we use the DEA common weights analysis method, i.e. we count all countries with the same weight as the scoring model. Our last ranking is linked to the multidimensional scaling method known from multivariate statistics. Namely, if we project our points from the multi-dimensional space to the straight line, that is to say, one-dimensionally, we get a sequence that we use. The next chapter compares these six types of ranking. The comparison suggests that the methods described provide a similar solution. The last, fifth chapter of the paper concludes the results.

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[1] I-DESI 2018: How digital is Europe compared to other major world economies? // European Commission 26.10.2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 04.06.2019).

[2] International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

1. Short Literature Review

The literature on measuring the development and impact of the digital economy and society is very diverse and we only attempt to provide a short overview of some of the relevant themes that have been explored in this context. A recent study by a joint Czech-Latvian teamanalyzed ICT-relatedhuman capital elements and government policies in the Czech Republic and Latvia, finding that there was no statistically significant difference in adults' readiness to study online between the two countries [Mirke, Kasparova, Cakula, 2019]. A paper of Götzanalyzed the impact of Industry 4.0 on German-Polish economic relations. The author concludes in herwork that the digital economy can have a positive effect on German-Polish relationships [Götz, 2017]. Another recent study by Silvaggi and Pesce looked at how digitalization and the digital economy "can win" in Portugal, Italy and Greece. Their research focused on the impact of digitization on museums, including the redemption of workplace skills [Silvaggi, Pesce, 2018].

Russian and Ukrainian scholars have also been fairly active in the field. Grytsulenko and Umanets evaluated the spread of the digital economy in an international context. The comparison was carried out with the involvement of the European Union, the Commonwealth of Independent States and Ukraine. Their analysis was mainly done by processing the available statistical data [Grytsulenko, Umanets, 2018]. Another recent article by Belanova and co-authors sought to identify the main directions and indicators for the development of the digital economy. The authors carry out a comparative analysis of international indices related to Information and Communication Technologies (ICT) and digitalization, including the I-DESI [Belanova, Kornilova, Sultanova, 2020][3]. A paper of Afonasova, Panfilova and Galichkina analyzed indicators that characterize the level of digital sector development with a view to developing measures stimulating the digitalization process[Afonasova, Panfilova, Galichkina, 2018]. A recent study by Dobrulyova, Alexandrov and Yefremov aims to benchmark Russian ICT development with that in the EU countries and identify some important preconditions for the digital transformation. The authors conclude that Russia's lag in terms of connectivity, digital skills, and business adoption of digital technology is significant and is likely to further increase [Dobrolyubova, Alexandrov, Yefremov, 2017]. Finally, Petrenko and co-authors analyzed sub-indices of the international Networked Readiness Index (NRI) in order to understand the problems of transition to the digital economy in Russia and determine the ways to resolve them [Petrenko et al., 2017].

2. Measurement of the Digital Economy

Due to the pervasiveness of ICT, data about its application and impact is generated in unprecedented magnitudes. There are several indices, scores, indicators, measurement units that describe the status of the digital economy, society, public administration and used as descriptors of digital transformation.

Firstly, there are the scoring systems describing and comparing global impacts and situation in digitization. These are for instance the UN, OECD, World Bank or ITU re-

[3] Although the study is due to be published in 2020 as a book chapter, it is already available online from February 2019 at the publisher.

ports serving similar objectives as some major consulting firms' regular research projects such as Forrester, IDC, Gartner or McKinsey surveys.

The second category of these measures are the ones that focus on regional or well-defined country clusters belonging to a geopolitical area. Typical surveys of this kind are the EU scoreboards: the Digital Economy and Society Index (DESI)[4], Digital Skills Indicator (DSI)[5] or the Consumer Conditions Scoreboard (CCS)[6].

Finally, the third set of data that is collected for describing the ICT impacts are country specific collections usually carried out by National Statistical Offices or domestic research firms.

Although DESI is being debated by experts, and as we will show there are several problems of its method and collection system, it is still the most robust, unavoidable and arguably the best choice for describing European progress on digitalization.

The DESI reports track the progress made by Member States in terms of their digitization. They are structured around five chapters (Table 1).

Table 1. **Dimensions of DESI**

DESI Dimensions	Relevant policy areas and indicators
Connectivity	Fixed broadband, mobile broadband and prices
Human Capital	Internet use, basic and advanced digital skills
Use of Internet Services	Citizens' use of content, communication and online transactions
Integration of Digital Technology	Business digitization and e-commerce
Digital Public Services	eGovernment and eHealth

B a s e d o n: The Digital Economy and Society Index (DESI) // European Commission. URL: https://ec.europa.eu/digital-single-market/en/desi (accessed: 04.06.2019).

It is a widely used and quoted measurement system by the experts and policy makers but it certainly has its advantages and serious limitations. Its main advantage is that it is measured in 28 countries, and by doing so allows comparison, it is accepted by the European Union and allows compliance, and it provides the big picture of the digital ecosystem in the Union and the member countries.A separate dataset (International Digital Economy and Society, I-DESI) aims to mirror and extend the results of DESI to all 28 EU and 17 non-EU countries for benchmarking purposes.

Disadvantages are rooted from similar sources as advantages: the fact that measurements are collected in 28 different countries entails that the methodology is determined to be general and applicable in all. Therefore, the results are also fairly general and not suitable for deep analysis and explanation of certain phenomena. Specifically, major drawbacks are that measurement factors often have the impression of improvised choice in a

[4] The Digital Economy and Society Index (DESI) // European Commission. URL: https://ec.europa.eu/digital-single-market/en/desi (accessed: 04.06.2019).

[5] A new comprehensive Digital Skills Indicator // European Commission. URL: https://ec.europa.eu/digital-single-market/en/news/new-comprehensive-digital-skills-indicator (accessed: 04.06.2019).

[6] Consumer Scoreboards // European Commission. URL: https://ec.europa.eu/info/policies/consumers/consumer-protection/evidence-based-consumer-policy/consumer-scoreboards_en (accessed: 06.06.2019).

given year and they often change. It often seems biased by industry lobbies, the time between the data collection and publication is very long — resulting frequently in outdated assessments. Indicators and sub-indicators change year by year which makes it difficult to compare time series performances because these corrections are not emphasized enough. There are also significant differences between the statistical offices and data collection methods between countries and these problems are only exacerbated for the extended database[7].

3. Ranking of Countries Russia and EU–28

Our dataset (Table 2, fig. 1) was compiled from the I-DESI website[8]. The original dataset contains data from 45 countries: data from the EU–28 and data from 17 non-EU countries, including Russia. From this dataset, we collected data from the 28 EU Member States and supplemented with Russia's sub-indicators to obtain a dataset with 29 countries.The five indicators/variables were used for ranking analysis. We were looking for answers to the following questions with data envelopment analysis (DEA):

(a) what is the ranking with scoring model under known weights used in EU materials;
(b) are the results changed with basic DEA method; is DEA/CWA a robust method;
(c) is DEA/CWA a robust method;
(d) are the results with multidimensional scaling significant?

Since the $\underline{x}_i$ scores for the dimensions are calculated from a weighted sum of normalized individual indicators, the numbersin Table 2 "have little meaning as quantities in themselves"[9], but they should allow us to compare the relative performance of our 29 countries in each dimension and evaluate their overall digital competitiveness. Russia ranks 10th in the Human Capital dimension, 18–19th (tied with Poland) in Digital Public Services, 23rd in the Use of Internet, 28th in the Integration of Digital Technology and 29th in Connectivity.

The European Commission uses a weighted sum of these dimensions to calculate the DESI overall index (and their own ranking), but data envelopment analysis (DEA) and multidimensional scaling (MDS) offer viable alternative solutions to the aggregation/ranking problem, allowing us to test the robustness of their ranking. Six analyses are pre-

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7 The authors of the I-DESI 2018 report them selves note that although "the match-up between I-DESI and EU28 DESI indicators is generally good", "[p]erfection could only be achieved if the sample sizes and data collection methods used by national statistical agencies inEU28 Member States was replicated in other countries" (p. 30). They also add that "[g]iven a reliance on secondary data to build the 2018 I-DESI it was necessary tomake estimations to compensate for missing and incomplete data" (p. 33). International Digital Economy and Society Index 2018 // SMART 2017/0052 — Final Report. A study prepared for the European Commission DG Communications Networks, Content & Technology by Tech4i2 (Paul Foley, David Sutton, Ian Wiseman, Lawrence Green, Jake Moore). URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

8 International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

9 International Digital Economy and Society Index 2018 // SMART 2017/0052 — Final Report (p. 10). A study prepared for the European Commission DG Communications Networks, Content & Technology by Tech4i2 (Paul Foley, David Sutton, Ian Wiseman, Lawrence Green, Jake Moore). URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

sentedin this chapter. First, we determine the classical DESI overall index with the weights suggestedby the Commission. This investigation is known in the decision theory as a scoring model. The values in Table 3 are used for this.

Table 2. **The basic data ($\underline{x}_i$)**

Country	Code	Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
Austria	AT	0.63	0.59	0.60	0.59	0.72
Belgium	BE	0.68	0.60	0.62	0.61	0.61
Bulgaria	BG	0.61	0.47	0.42	0.36	0.45
Croatia	HR	0.54	0.45	0.49	0.46	0.56
Cyprus	CY	0.54	0.45	0.54	0.39	0.49
Czech Republic	CZ	0.67	0.58	0.58	0.39	0.43
Denmark	DK	0.77	0.80	0.79	0.71	0.71
Estonia	EE	0.62	0.66	0.70	0.53	0.85
Finland	FI	0.72	0.73	0.78	0.67	0.83
France	FR	0.59	0.62	0.59	0.53	0.82
Germany	DE	0.64	0.62	0.66	0.59	0.69
Greece	EL	0.50	0.48	0.46	0.45	0.48
Hungary	HU	0.60	0.62	0.55	0.51	0.46
Ireland	IE	0.63	0.77	0.56	0.51	0.66
Italy	IT	0.51	0.50	0.42	0.47	0.68
Latvia	LV	0.65	0.47	0.58	0.32	0.56
Lithuania	LT	0.61	0.53	0.58	0.46	0.63
Luxembourg	LU	0.65	0.67	0.79	0.77	0.64
Malta	MT	0.64	0.48	0.57	0.57	0.66
Netherlands	NL	0.75	0.69	0.76	0.75	0.76
Poland	PL	0.53	0.53	0.51	0.33	0.57
Portugal	PT	0.60	0.43	0.47	0.39	0.55
Romania	RO	0.61	0.43	0.48	0.27	0.39
Russia	RU	0.39	0.64	0.49	0.30	0.57
Slovakia	SK	0.57	0.65	0.59	0.40	0.38

End of Table 2

Country	Code	Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
Slovenia	SI	0.60	0.44	0.53	0.43	0.67
Spain	ES	0.64	0.62	0.58	0.55	0.82
Sweden	SE	0.75	0.69	0.78	0.65	0.73
United Kingdom	UK	0.74	0.65	0.72	0.68	0.90

B a s e d o n: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

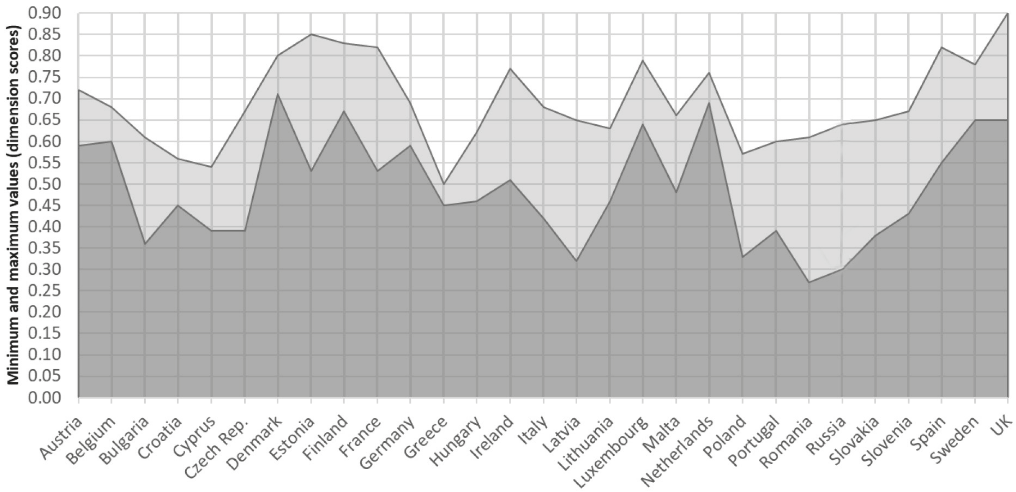

Fig. 1. Spread of the basic data

N o t e: see Table 2.

B a s e d o n: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

Table 3. **The weights of the variables for DESI overall index (vector w)**

Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
0.25	0.25	0.15	0.2	0.15

B a s e d o n: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

We then place the DEA model at the center of the analysis. In the DEA model, the sub-indicators (criteria) are divided into two groups: input and output criteria. The input criteria are connectivity and human capital, while the output criteria are use of Internet, integration of digital technology and digital public services[10]. However, we need to transform our data, because in the case of our two input criteria, we have to convert the best maximum value to the minimum. This can be achieved in two ways: by reciprocating the criteria values or by linear transformation. Both methods are used to analyze whether they give significantly differingresults.

Similarly, we perform the data envelopment analysis/common weights analysis (DEA/CWA) with two different data sets. The advantage of this method is that we do not have to solve 29 linear programming problems in our case, only one, and we take the data of all countries into account with the same weight.

Finally, multidimensional scaling is projected to a one-dimensional one, giving us a ranking.

3.1. DESI Overall Indices for the Given 29 Countries with Scoring Model

In decision theory [Parmigiani, Inoue, 2009], scoring models assign value to decision making units (DMU) to multiply the given criteria with a predetermined weight vector. Suppose that for weight vector $\underline{w}$ the i^{th} DMU values along the criteria are vector $\underline{x}_i$. Then we assign a $\underline{w}\cdot\underline{x}_i$ value to i^{th} DMU:

$$F_i = \underline{w} \cdot \underline{x}_i = \sum_{j=1}^{m} w_j \cdot x_{ji} \quad (i = 1, 2, \ldots, n).$$

where the number of criteria is m and the number of DMU's is n. The values F_i are then the DESI overall indices.

The indices are contained in Table 4. The countries with the top rankingsare Denmark, Netherlands, and Finland. Russia ranks 26th, outperforming Greece, Bulgaria, and Romania, which are the countries with the least favorable rankings.

3.2. Basic DEA Model with Reciprocal Values of Input Criteria

The DEA method is a general framework to evaluate countries in the absence of weights of the criteria. The basic method was initiated by Charnes with co-authors to determine the efficiency of decision-making units (DMU) [Charnes, Cooper, Rhodes, 1978; Charnes et al., 2013]. The model offered by them is a hyperbolic programming model under linear conditions. A general solution method for this kind of model was first investigated by Martos, who examined the problem as a special case of linear programming models [Martos, 1964]. The aim of the DEA model is to construct the weights for the input and output criteria. The weights are vectors v and u for the input and output criteria. Let

[10] The delineation of input and output criteria was based on the characteristics of their sub-dimensions and individual indicators. The DESI 2018 methodological note also suggests that Connectivity and Human Capital "represent the infrastructure of the digital economy and society", while the other dimensions "are enabled by the infrastructure and their contribution is strengthened by the quality of such infrastructure" (p. 18). DESI 2018 Digital Economy and Society Index. Methodological note // European Commission. URL: http://ec.europa.eu/information_society/newsroom/image/document/2018-20/desi-2018-methodology_E886EDCA-B32A-AEFB-07F5911DE975477B_52297.pdf (accessed: 04.06.2019).

us formulate the DEA model in the next form, assuming that we examine the efficiency of the 1st decision making unit:

$$u \cdot y_1 / v \cdot x_1 \rightarrow \max \quad (1)$$

s.t.

$$u \cdot y_j / v \cdot x_j \leq 1; j = 1, 2, \ldots, 29. \quad (2)$$

$$u \geq 0, v \geq 0. \quad (3)$$

— (3) is the basic DEA method, which can be reformulated in a linear programming model (LP) in the following form:

$$u \cdot y_1 \rightarrow \max \quad (4)$$

s.t.

$$v \cdot x_1 = 1, \quad (5)$$

$$u \cdot y_j - v \cdot x_j \leq 0; j = 1, 2, \ldots, 29. \quad (6)$$

$$u \geq 0, v \geq 0. \quad (7)$$

(4)–(7) can be solved with commercial software, e. g., with Microsoft Excel Solver. Throughout the paper, we apply this software to construct our calculations.

The input criteria/variables of the evaluation are Connectivity and Human Capital, while the outputs are Use of Internet Services, Integration of Digital Technology, and Digital Public Services. To determine the efficiencies of countries, 29 linear programming (LP) problems must be solved.

First, let us transform the values of the input criteria. The new input values are equal to $x'_{ji} = 1 / x_{ji}$. The new transformed values are shown in Appendix (Table 1).

After obtaining the results of 29 LP problems, the DEA efficiencies are presentedin Table 4.

The best countries are still Denmark, Finland, and theNetherlands. The worst countries on the field are Croatia, Bulgaria, and Greece. In this case, Romania and Russia perform considerably better, with the latter ranking 20th.

Table 4. **The calculated rankings**

Country	DESI overall index (scoring)		Efficiencies with DEA (reciprocal)		Efficiencies with DEA (on a scale)		Efficiencies with DEA/CWA (reciprocal)		Efficiencies with DEA/CWA (on a scale)		MDS values	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Austria	0.621	12	0.727	13	0.128	12	0.697	11	0.128	10	–0.462	11
Belgium	0.627	11	0.738	11	0.143	10	0.717	10	0.131	8	–0.422	13
Bulgaria	0.473	28	0.451	28	0.030	28	0.451	27	0.030	26	1.241	28
Croatia	0.497	22	0.479	27	0.046	25	0.478	24	0.046	21	0.789	20

Country	DESI overall index (scoring)		Efficiencies with DEA (reciprocal)		Efficiencies with DEA (on a scale)		Efficiencies with DEA/CWA (reciprocal)		Efficiencies with DEA/CWA (on a scale)		MDS values	
	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank	Value	Rank
Cyprus	0.480	25	0.481	26	0.031	26	0.481	23	0.031	24	0.999	25
Czech Rep.	0.542	17	0.639	15	0.077	18	0.598	18	0.036	22	0.748	19
Denmark	0.760	1	1.000	1	1.000	1	1.000	1	1.000	1	–1.660	1
Estonia	0.659	7	0.926	6	0.170	8	0.804	7	0.164	7	–0.959	7
Finland	0.738	3	1.000	1	0.382	5	0.985	3	0.382	5	–1.545	2
France	0.620	13	0.839	9	0.131	11	0.686	12	0.131	9	–0.582	9
Germany	0.636	8	0.737	12	0.126	13	0.735	9	0.126	11	–0.568	10
Greece	0.476	27	0.414	29	0.031	27	0.400	28	0.025	27	1.045	26
Hungary	0.559	15	0.559	22	0.060	21	0.529	19	0.032	23	0.431	16
Ireland	0.635	9	0.839	10	0.339	6	0.645	14	0.108	14	–0.461	12
Italy	0.512	21	0.566	21	0.065	20	0.454	26	0.065	18	0.705	18
Latvia	0.515	20	0.636	16	0.083	17	0.636	15	0.083	17	0.823	21
Lithuania	0.559	16	0.626	17	0.086	16	0.626	16	0.086	16	0.208	15
Luxembourg	0.699	6	0.914	7	0.161	9	0.814	6	0.115	12	–1.341	5
Malta	0.579	14	0.684	14	0.115	14	0.662	13	0.115	13	-0.065	14
Netherlands	0.738	2	1.000	1	0.570	3	0.975	5	0.570	3	–1.536	4
Poland	0.493	23	0.500	24	0.047	24	0.484	22	0.047	20	0.917	23
Portugal	0.489	24	0.514	23	0.058	22	0.514	20	0.058	19	0.962	24
Romania	0.445	29	0.481	25	0.023	29	0.465	25	0.012	28	1.572	29
Russia	0.477	26	0.602	20	0.066	19	0.348	29	0.030	25	1.222	27
Slovakia	0.531	18	0.607	18	0.056	23	0.496	21	0.007	29	0.912	22
Slovenia	0.526	19	0.604	19	0.093	15	0.600	17	0.093	15	0.516	17
Spain	0.635	10	0.849	8	0.174	7	0.737	8	0.174	6	–0.659	8
Sweden	0.717	5	0.976	5	0.528	4	0.976	4	0.528	4	–1.294	6
UK	0.727	4	1.000	1	0.613	2	1.000	1	0.613	2	–1.537	3

Based on: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

3.3. Basic DEA Model with Linearly Transformed Values of Criteria

The transformation of the basic data is based on a utility function. The utility functions of criteria have a range between 1 and 20. For the input, data we have chosen the function

$$U_{ij} = \frac{19}{x_j^{max} - x_j^{min}} \cdot x_{ij} - 19 \cdot \frac{x_j^{max}}{x_j^{max} - x_j^{min}} - 1,$$

where value x_j^{max} is the most preferable value of criterion j, and value x_j^{min} is the worst value of this criterion. For the output data we have developed

$$U_{ij} = \frac{19}{x_j^{max} - x_j^{min}} \cdot x_{ij} - 19 \cdot \frac{x_j^{max}}{x_j^{max} - x_j^{min}} + 20,$$

where value x_j^{max} is the most preferable value of criterion j, and value x_j^{min} is the worst value of this criterion. The used transformation is an affine one, as analysed by Färe and Grosskopf [Färe, Grosskopf, 2013]. (See Appendix, Table 2 for the transformed values.)

After obtaining the results of 29 LP problems, the DEA efficiencies are presented in Table 4.

Denmark and the Netherlands retain their place in the top three, but in this case, they are joined by the United Kingdom instead of Finland. Greece, Bulgaria and Romania are at the bottom, and Russia ranks 19th, outperforming several Eastern and Southern European EU countries.

3.4. The DEA Common Weights Analysis (DEA/CWA) Model with Reciprocal Values of Input Criteria

Regarding the basic model of DEA, the question arises as to why each decision making unit (DMU) should be evaluated with different weights. This means that as many linear programming problems must be solved as the number of DMUs. In contrast, the DEA/CWA model is based on the assumption that it is sufficient to solve only a single LP problem with which we evaluate each DMU with the same weights. The purpose of LP is then to minimize the sum of differences between the outputs and the inputs for all DMUs.

Let us use the linear programming problem (4)–(7) for the case, when the sum of inequalities (6) is maximized. The problem (4)–(7) can be reformulated in the following form (4′)–(7′):

$$u \cdot Y \cdot \mathbf{1} - v \cdot X \cdot \mathbf{1} \rightarrow \max \quad (4')$$

s.t.

$$v \cdot \mathbf{1} = 1, \quad (5')$$

$$u \cdot Y - v \cdot X \leq 0, \quad (6')$$

$$u \geq 0,\ v \geq 0. \quad (7')$$

In problem (4′)–(7′) vectors **1** are the summation vectors with elements one, matrices Y and X are the input and output matrices of the decision making units in the following form

$$Y = [y_1, y_2, \ldots, y_p],\ X = [x_1, x_2, \ldots, x_p].$$

Equality (5′) guarantees the boundedness of the set of the weights. Inequalities (6′) subsume the efficiency indices. Goal function (4′) summarizes the deviations from the maximal efficiency. The solution of problem (4′)–(7′) are the common weights for our problem. The next, second phase determines the efficiency of the decision making units. The optimal solution and the efficiencies are presented in Table 4.

The country with the best ranking is still Denmark, joined by the UK at the top. Russia ranks 29th, below Greece and Bulgaria.

3.5. The DEA Common Weights Analysis (DEA/CWA) Model with Linearly Transformed Data

Solve problem (4′)–(7′) now with numbers in Appendix 2 (Table 2). The optimum efficiencies are in Table 4.

Denmark is first in this ranking as well, while now Slovakia is at the bottomwith Russia ranking 25th.

3.6. Ranking with Multidimensional Scaling (MDS)

Multidimensional Scaling is a well-known multivariate statistical method. The essence of the method is to map points from a higher dimensional space to a lower dimensional space so that the distances are kept as high as possible. If the MDS method is mapped into one-dimensional space, that is to say the line, then we get a sequence if the distances in the two spaces are well correlated.

Table 4 shows the distances received. The method's stress is 0.24235, which can be called good. Correlation between the distances of the two spaces, i.e. the *R* square, is 0.902, which is strong enough to be regarded as a sequence at the same time. In the ranking, Denmark is still on top, Russia is in 27th place above Bulgaria and Romania.

4. Comparison of the Results

The rankings obtained with DEA and multidimensional scaling are very similar to each other andtheranking using the original DESI weights (as evidenced by the fairly strong correlations between them), indicating their robustness. The rankings according to the DEA efficiencies, MDS values and DESI overall indices are presented below in Table 4, fig. 2 while the correlations between the ranking methodsused in our study areshown in Appendix (Table 3).

For most countries, the rankingis fairlystable regardless of which method is used, with Denmark ranking first in all of them. For Russia, however, it exhibitswider variation, asthe country ranks as high as 19th if the basic DEA model is used with linearly transformed data, but only 29th according to the DEA/CWA model with reciprocal data.

Conclusions

The paperdescribes the structure of the Digital Economy and Society Index with its five principal dimensions. The aim was to compare the indices of Russia and the 28 member states of European Union with the available data. We created six indices: the DESI

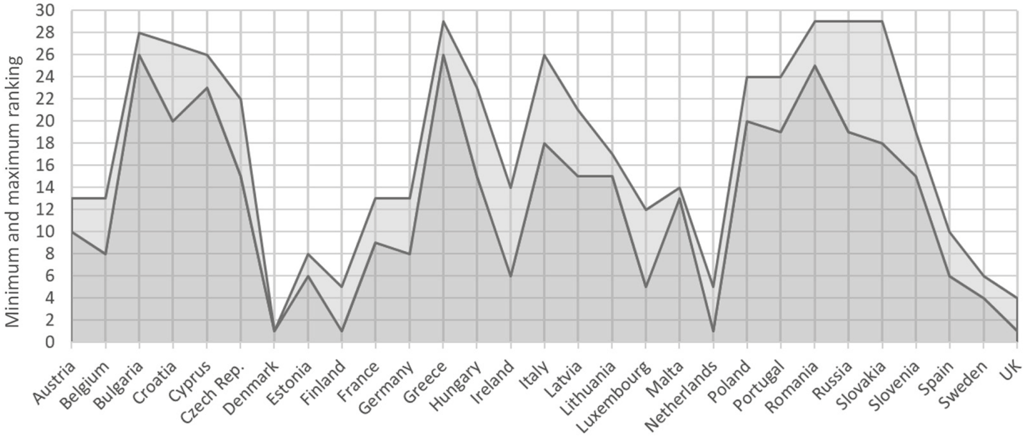

Fig. 2. Spread of the extreme rankings

N o t e: see Table 4.

B a s e d o n: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

overall index, two efficiency indicators that can be determined by the DEA method, two DEA/CWA indicators, and finally an index of the multidimensional scaling of multivariate statistics.

Comparing the six indicators shows that the sequences exhibitvery similar results. This may also mean that weights for DESI do not significantly affect the order of countries. In our calculations, Russia is part of the last third of EU countries in digital development, although their ranking shows marked variation. Where Russia is considered to be strong is the dimension of Human Capital. This is the reserve that the country can draw onin the digital economy.

Future research should answer the question of how the results can contribute to the formulation of policy recommendations. To do this, the five dimensions of DESI should be examined in terms of how to improve the coherence of dimensions. It is also advisable to examine additional methods for conducting the ranking because the scoring model does not differentiate countries sufficiently if there is redundancy between the data.

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Appendix

Table 1. **The reciprocally transformed data**

Country	Code	Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
Austria	AT	1.59	1.69	0.60	0.59	0.72
Belgium	BE	1.47	1.67	0.62	0.61	0.61
Bulgaria	BG	1.64	2.13	0.42	0.36	0.45
Croatia	HR	1.85	2.22	0.49	0.46	0.56
Cyprus	CY	1.85	2.22	0.54	0.39	0.49
Czech Republic	CZ	1.49	1.72	0.58	0.39	0.43
Denmark	DK	1.30	1.25	0.79	0.71	0.71
Estonia	EE	1.61	1.52	0.70	0.53	0.85
Finland	FI	1.39	1.37	0.78	0.67	0.83
France	FR	1.69	1.61	0.59	0.53	0.82
Germany	DE	1.56	1.61	0.66	0.59	0.69
Greece	EL	2.00	2.08	0.46	0.45	0.48
Hungary	HU	1.67	1.61	0.55	0.51	0.46
Ireland	IE	1.59	1.30	0.56	0.51	0.66
Italy	IT	1.96	2.00	0.42	0.47	0.68
Latvia	LV	1.54	2.13	0.58	0.32	0.56
Lithuania	LT	1.64	1.89	0.58	0.46	0.63
Luxembourg	LU	1.54	1.49	0.79	0.77	0.64
Malta	MT	1.56	2.08	0.57	0.57	0.66
Netherlands	NL	1.33	1.45	0.76	0.75	0.76
Poland	PL	1.89	1.89	0.51	0.33	0.57
Portugal	PT	1.67	2.33	0.47	0.39	0.55
Romania	RO	1.64	2.33	0.48	0.27	0.39
Russia	RU	2.56	1.54	0.49	0.30	0.57
Slovakia	SK	1.67	2.27	0.59	0.40	0.38
Slovenia	SI	1.56	1.61	0.53	0.43	0.67
Spain	ES	1.33	1.45	0.58	0.55	0.82
Sweden	SE	1.35	1.54	0.78	0.65	0.73
United Kingdom	UK	1.59	1.69	0.72	0.68	0.90

Based on: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index-2018 (accessed: 05.06.2019).

Table 2. **The linearly transformed data**

Country	Code	Connectivity	Human Capital	Use of Internet	Integration of Digital Technology	Digital Public Services
Austria	AT	–8.00	–11.78	10.24	13.16	13.42
Belgium	BE	–5.50	–11.27	11.27	13.92	9.40
Bulgaria	BG	–9.00	–17.95	1.00	4.42	3.56
Croatia	HR	–12.50	–18.97	4.59	8.22	7.58
Cyprus	CY	–12.50	–18.97	7.16	5.56	5.02
Czech Republic	CZ	–6.00	–12.30	9.22	5.56	2.83
Denmark	DK	–1.00	–1.00	20.00	17.72	13.06
Estonia	EE	–8.50	–8.19	15.38	10.88	18.17
Finland	FI	–3.50	–4.59	19.49	16.20	17.44
France	FR	–10.00	–10.24	9.73	10.88	17.08
Germany	DE	–7.50	–10.24	13.32	13.16	12.33
Greece	EL	–14.50	–17.43	3.05	7.84	4.65
Hungary	HU	–9.50	–10.24	7.68	10.12	3.92
Ireland	IE	–8.00	–2.54	8.19	10.12	11.23
Italy	IT	–14.00	–16.41	1.00	8.60	11.96
Latvia	LV	–7.00	–17.95	9.22	2.90	7.58
Lithuania	LT	–9.00	–14.86	9.22	8.22	10.13
Luxembourg	LU	–7.00	–7.68	20.00	20.00	10.50
Malta	MT	–7.50	–17.43	8.70	12.40	11.23
Netherlands	NL	–2.00	–6.65	18.46	19.24	14.88
Poland	PL	–13.00	–14.86	5.62	3.28	7.94
Portugal	PT	–9.50	–20.00	3.57	5.56	7.21
Romania	RO	–9.00	–20.00	4.08	1.00	1.37
Russia	RU	–20.00	–9.22	4.59	2.14	7.94
Slovakia	SK	–11.00	–8.70	9.73	5.94	1.00
Slovenia	SI	–9.50	–19.49	6.65	7.08	11.60
Spain	ES	–7.50	–10.24	9.22	11.64	17.08
Sweden	SE	–2.00	–6.65	19.49	15.44	13.79
United Kingdom	UK	–2.50	–8.70	16.41	16.58	20.00

Based on: International Digital Economy and Society Index 2018. URL: https://ec.europa.eu/digital-single-market/en/news/international-digital-economy-and-society-index–2018 (accessed: 05.06.2019).

Table 3. **Correlations between the DESI, DEA and MDS scores**

		DEA (reciprocal)	DEA (on a scale)	DEA/CWA (reciprocal)	DEA/CWA (on a scale)	MDS values
DESI overall index	Pearson Correlation	.968**	.810**	.961**	.791**	–.991**
	Sig. (2-tailed)	.000	.000	.000	.000	.000
DEA (reciprocal)	Pearson Correlation		.785**	.940**	.757**	–.959**
	Sig. (2-tailed)		.000	.000	.000	.000
DEA (on a scale)	Pearson Correlation			.821**	.981**	–.773**
	Sig. (2-tailed)			.000	.000	.000
DEA/CWA (reciprocal)	Pearson Correlation				.829**	–.952**
	Sig. (2-tailed)				.000	.000
DEA/CWA (on a scale)	Pearson Correlation					–.761**
	Sig. (2-tailed)					.000

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Сравнительный анализ развития цифровой экономики в России и ЕС: приложение метода DEA к данным индекса DESI

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Целью работы является сравнение развития цифровой экономики в России и в 28 странах Европейского союза. Данные были собраны из базы данных Международного индекса цифровой экономики и общества (I-DESI 2018) Европейской комиссии. В статье после краткого обзора различных альтернативных способов измерения воздействия информационных и коммуникационных технологий рассмотренынаиболее важные особенности, преимущества и недостатки этой базы данных. Затем описана структураисследуемого набора данных и проведен анализ цифровой конкурентоспособности России и ЕС–28. Основные вопросы исследования касаются надежности данных ЕС и стабильности их рейтинга. Для этого использован метод анализа охвата данных (DEA) и одномерная версия многомерного масштабирования, которая также может применяться для ранжирования вопросов. В дополнение к обычному методу DEA исследуется жизнеспособность моделей DEA с общим весом. Для ответа на поставленные в работе вопросы полученные результаты сравниваются. Их оценка показывает, насколько данные из России соответствуют данным ЕС в цифровой экономике. Сравнение демонстрирует, что методы, использованные в нашем исследовании, дают аналогичное решение, но для рейтинга нескольких стран (включая Россию) характерен более широкий разброс.

Ключевые слова: индекс DESI, цифровое государственное управление, инновации, анализ охвата данных, многомерное масштабирование, ранжирование.

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