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THE MEASUREMENT OF INDUSTRY 4.0: AN EMPIRICAL CLUSTER ANALYSIS FOR EU COUNTRIES

PAVLÍNA HEJDUKOVÁ, LUCIE KUREKOVÁ, MICHAELA KRECHOVSKÁ

Abstract:

Based on findings regarding existing indicators for measuring Industry 4.0, the goal of this article is to develop a composite indicator and conduct a cluster analysis for EU countries. There is a relatively large body of academic research on the measurement of Industry 4.0, focusing on composite indicators that attempt to capture this phenomenon statistically. However, there are currently no available time series for these indicators. In the empirical section, we construct a new indicator—the "Industry 4.0 Relative Performance Index"—which is computed using the methodology of the World Economic Forum. The development of this composite indicator makes it possible to track Industry 4.0 performance over time and evaluate the relative positions of member states. Cluster analysis is conducted for the years 2011 and 2019, using data from Eurostat and World Bank statistics. The results of this paper may serve as guidance for future targeting of EU cohesion policy in the field of Industry 4.0 support, which may contribute to strengthening the position of the EU economy as a whole.

Keywords:

Industry 4.0, Fourth Industrial Revolution, measurement, indicators, cluster analysis

JEL Classification: O30, C38, O43

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Introduction

Terms like “new industrial revolution”, “the Fourth Industrial Revolution” and “Industry 4.0” are used often as of late. Each industrial revolution has brought with it advantages and new challenges for socioeconomic status and this is no different for the Fourth Industrial Revolution, in which the term Industry 4.0 plays a significant role.

The term Industry 4.0 comes from Germany, where it was presented as “Industrie 4.0”, and already in 2012 the Government of Germany created the Industry 4.0 working group. This group built a platform aimed at developing the concepts of new technologies for the future (Tomek & Vávrová, 2017). As stated above, the concept of Industry 4.0 is linked with the so-called “Fourth Industrial Revolution”, which builds upon the Third Industrial Revolution (i.e. the digital revolution) that has been occurring since the middle of the last century. The Fourth Industrial Revolution is characterized by a fusion of technologies that connects the lines between the physical, digital, and biological spheres (Swab, 2016A).

The characteristics of the concept of the Fourth Industrial Revolution or Industry 4.0 are not unified, and selected approaches are listed in Tables 1 and 2.

Table 1: Approaches towards defining the Fourth Industrial Revolution

Author(s)	**Definition**
(Piccarozi et al., 2018)	The Fourth Industrial Revolution is based on the development of a completely automated and intelligent production, capable of communicating autonomously with the main corporate players.
(Sommer, 2015)	The Fourth Industrial Revolution will lead to full automation and digitalization processes, and the use of electronics and information technologies (IT) in manufacturing and services in a private environment.
(Buguin et al., 2013)	The Fourth Industrial Revolution as the age of “cyber–physical systems” – systems that integrate computation, networking, and physical processes.
(Swab, 2016B)	The Fourth Industrial Revolution is evolving at an exponential rather than linear pace that not only changes the “what” and the “how” of doing things, but also “who” we are.
(Morrar et al., 2017)	The Fourth Industrial Revolution is the spread of technologies with the assumption of exponential growth due to technological changes and significant socioeconomic impact.

Source: own research based on studies of authors mentioned above

Table 2: Approaches towards defining Industry 4.0

Author(s)	**Definition**
(Dutton, 2014)	Industry 4.0 is related to what is called the “smart factory”.
(Kagermann & Wahlster, 2014)	Industry 4.0 is the IoT: data and services that will change future production, logistics, and work processes.

Author(s)	Definition
(PwC, 2017)	Industry 4.0 is a framework, which also was adopted by the Flemish Government. The idea of the framework arose by asking leading companies to determine their priorities among a group of concepts. Smart systems, humans in Industry 4.0, smart production, and people skills were identified as the highest priorities
(Pan et al., 2015)	Industry 4.0 represents the ability of industrial components to communicate with one another.
(Kovács & Kot, 2016)	The essence of Industry 4.0 conception is the introduction of network-linked intelligence systems, which realize self-regulating production: people, machines, equipment and products will communicate with one other.

Source: own research based on studies of authors mentioned above

Industry 4.0 has an important influence on the transformation of industry as a result of the following three signs of progress: (i) The digitalization of production and information systems (ii) the automation of systems and (iii) automatic data interchange (see Almada-Lobo, 2015; Schlechtendahl et al., 2015). Authors Atik & Uhlu (2019) point to the fact that the digitalization of production and information systems is a necessary development for management and the planning of production. Acquiring data from the production line requires the automation of systems. Automatic data interchange helps link manufacturing sites in a supply chain. According to Greengard (2016), Industry 4.0 has four main components: (i) Cyber Physical Systems, (ii) the Internet of Things (IoT), (iii) the Internet of Services (IoS) and (iv) the Smart Factory.

The aforementioned shows that, in regard to the non-uniformity of characteristic terms surrounding the Fourth Industrial Revolution and Industry 4.0, it is not easy to describe this complex phenomenon, no less record it with the help of statistics.

The primary problem in the area of statistically recording Industry 4.0 is the fact that only one simple indicator is usually insufficient, and it is necessary to construct more complex indicators. The next problem is the fact that the composite indicator timelines for Industry 4.0 are usually missing. These indicators are not usually firmly established methodologically or known to the public. There are studies that have attempted to construct their own Industry 4.0 indicators, but they usually lack recordings of the development of these indicators in time, see Atik & Unlu (2019) or Berger (2015).

Therefore, based on findings of existing indicators for the measurement of Industry 4.0, the goal of this article is to create our own composite indicator and carry out a cluster analysis for EU countries.

This article first provides a literature review that focuses on indicators used for the measurement of Industry 4.0 primarily based on desk research methods and serves as a basis for the creation of our own composite indicator in the context of the measurement of Industry 4.0, thus fulfilling the set goal of the paper. Methodology and data used to create the composite indicator are presented, and a cluster analysis is carried out. Research results are then presented and the paper's conclusion gives a summary of the issue at hand.

Literature Review – Indicators of the Measurement of Industry 4.0

Indicators for the measurement of Industry 4.0 are rather rare in research and scientific publications, and if they are dealt with, it is only in a very limited manner (they lack longer timelines, follow-up research, etc.). We can claim that indicators can be divided into simple or composite indicators.

Probably the simplest is the measurement of the performance of a given segment, i.e. Industry 4.0, the performance of Industry 4.0 with the use of simple indicators or statistical indicators such as the *percentage of the processing industry in GDP* or *the percentage of the ICT sector on GDP*. These examples of possible indicators stem from the fact that the processing industry has a fundamental significance in industry on the EU level (Mráček, 2017), as industry as a whole in the European Union generates 24% of the EU-28's GDP and provides employment to around 50 million people, i.e. roughly one fifth of employed individuals in EU member states (for more see European Commission, 2017). In addition, as the term Industry 4.0 is often linked to the term digitalization, the ICT sector thus plays a very significant role in this concept (for more e.g. Perakovic et. al. 2020; Xu et al., 2018; Santos et al., 2017). Another simple indicator in terms of the measurement of Industry 4.0 could also be the *percentage of innovative industrial enterprises in the overall number of enterprises*. Here it is necessary to mention that the possibility of using this indicator stems from the fact that innovation plays a fundamental role in industry (for more see Müller, 2017; Klímová & Žítek, 2015).

The advantage of simple indicators is that they are relatively available, they usually have a clear methodological basis, and thus their interpretation is relatively clear. The disadvantage is that they do not record the complexity of the researched phenomenon, and therefore these indicators can be used more as input information for composite indicators.

Industry 4.0 is a complex phenomenon and cannot be easily recorded statistically with one indicator; therefore, the need to compute these so-called composite indicators has arisen. Studies dealing with composite indicators of Industry 4.0 usually carry out a cluster analysis. The disadvantage of composite indicators in relation to Industry 4.0 may be the fact that there are still no timelines, as new phenomena that have not been studied before are arising and have not been statistically recorded, e.g. big data analysis, 3D printing and robotics.

In academic literature, we find a relatively large amount of composite indicators for the measurement of Industry 4.0, and these composite indicators usually record so-called Industry 4.0 readiness or Industry 4.0 performance. Nick & Pongrácz (2016) measured the relative readiness of cities using an index called the Smart Collaboration Index. Kuruczleki et al. (2016) determined the readiness of the European Union to embrace the fourth industrial revolution by developing a readiness index containing eight indicators. Atik & Ünlü (2019) measured the relative performance of the countries in transition towards Industry 4.0 by using level indicators such as big data, CCS and CPS. Based on an analysis of a study by Berger (2015), one advantage of the use of a composite indicator can be defined, as this survey was extensive and created its own indicator. We can also find a disadvantage in the fact that it was a one-time study without a follow-up to additional studies and therefore progress in research cannot be determined, i.e. replicating the research would be problematic.

As was mentioned above, the term Industry 4.0 is mainly linked to digitalization. And, in connection with digitalization, new indicators have arisen, such as the Digital Transformation Scoreboard, Digital Economy and Society Index (DESI), Networked Readiness Index, Index of Digitalization's Threat to the Labor Market, and so forth.

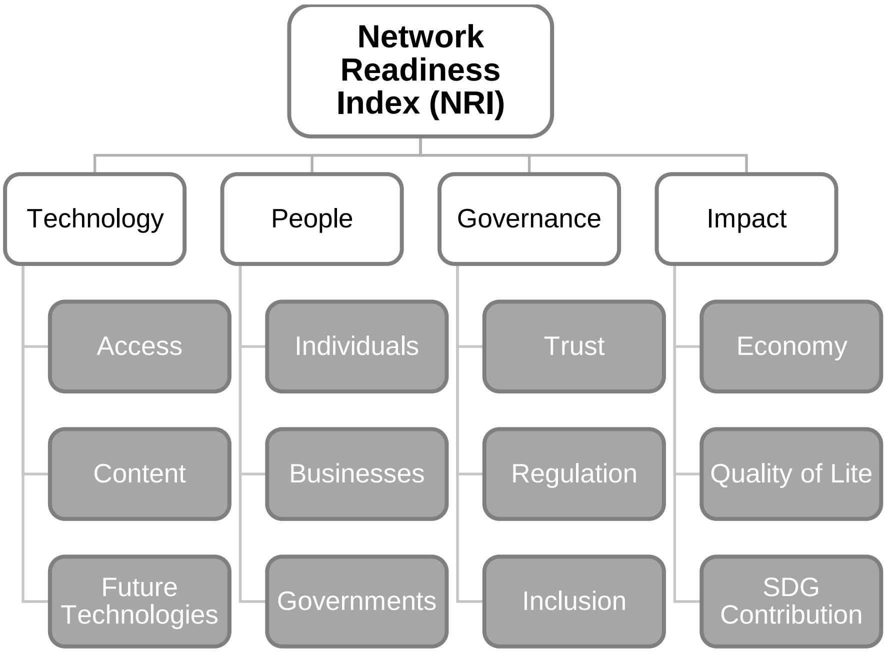
The Digital Transformation Scoreboard shows the integration of digital technologies. It is an adoption of digital technologies in businesses across the EU. It screens national policies and analyses a wide range of national data using a macro-perspective approach sourced from Eurostat, national statistics offices and international organizations. For 2018, case studies in this area focused on companies of the food and construction sectors (European Commission, 2018).

The Digital Economy and Society Index (DESI) is a composite index that summarizes relevant indicators of Europe’s digital performance and tracks the evolution of EU Member States in digital competitiveness. The International Digital Economy and Society Index (I-DESI) mirrors and extends the EU28 Digital Economy and Society Index by utilizing 24 datasets to enable trend analysis and comparison of the digital performance of 45 countries. As stated by the European Commission (2019), this indicator includes 5 studied dimensions:

- Connectivity - this dimension measures the deployment of broadband infrastructure and its quality. Access to fast and ultrafast broadband-enabled services is a necessary condition for competitiveness.
- Human capital / Digital Skills – this dimension measures the skills needed to take advantage of the possibilities offered by digital.
- Use of the Internet Services – this dimension accounts for a variety of online activities, such as the consumption of online content (videos, music, games, etc.), video calls, online shopping and banking.
- Integration of Digital Technology – this dimension measures the digitization of businesses and e-commerce. By adopting digital technologies, businesses can enhance efficiency, reduce costs and better engage customers and business partners. Furthermore, the Internet as a sales outlet offers access to wider markets and potential for growth.
- Digital Public Services – this dimension measures the digitization of public services, focusing on eGovernment and eHealth. Modernization and digitization of public services can lead to efficiency gains for the public administration, citizens and businesses alike.

The Networked Readiness Index evaluates the application and use of information and communication technologies (ICT). The redesigned NRI for 2019 is based on four pillars: Technology, People, Governance and Impact (Portulans Institute, 2019).

Figure 2: The NRI 2019 model



Source: Portulans Institute (2019)
Note: SDG = Sustainable Development Goal.

Chmelař et al. (2015) present the Index of Digitalization's Threat to the Labor Market in a study. This index replicated the methodology of existing advanced studies on the Czech labor market by creating a so-called „index of digitalization's threat to present professional categories in a time frame of fifteen to twenty years. The index primarily stems from a study by Frey & Osborne (2013) and, by utilizing an algorithm using the Gaussian process, it redistributes index values and attributes probabilities to individual professions. While calculating the overall number of new and now-defunct job positions, this study assumes an isolated impact that does not include calculations of the indirect capital impacts of a heightened operating surplus and its resulting positive impact on the degree of investments, the need for investment income and thus the additional creation of jobs.

Methodology and data

Based on an analysis of scientific literature (i.e. desk research), we have created our own composite indicator – the "Industry 4.0 relative performance index". This index has been computed using the methodology of the World Economic Forum, and the approach has also been used by e.g. Atik & Ünlü (2019). Basically, secondary indicators are used to calculate the new indicator, while the basic formula has the following form:

$$component_n^{it} = \frac{v_n^{it} - \min(v^{it})}{\max(v^{it}) - \min(v^{it})} \quad (1)$$

The letter *I* represents the selected variable, *n* represents the selected EU member state, and *t* determines the selected year of analysis. Thus v_n^{it} is the value of the selected statistical indicator *I* for the given state *n* in time *t.* $\text{Min}(v^{it})$ represents the minimum statistical indicator and the value in sample *n* and, analogically, $\max(v^{it})$ represents the maximum value. Contrary to Atik & Ünlü (2019), the spectrum of selection of secondary indicators for the calculation of the Industry 4.0 relative performance index is wider; these aforementioned authors have focused only on statistics concerning the integration of internal processes. Selected indicators in this study attempt to encompass three progresses that are linked to Industry 4.0 (see Almada-Lobo, 2015; Schlechtendahl et al., 2015). Indicators used for the calculation of the Industry 4.0 relative performance index are presented in Table 3 and an overview of values of input statistical indicators is presented in Table 4.

Table 3: Indicators used to calculate Industry 4.0 Index (% of total enterprises)

CODE	Variable name (i)		Years	
(a)	Share of industry in the economy	% GDP	2011	2017
(b)	Enterprises that have either introduced an innovation or have some kind of innovation (including enterprises with abandoned/suspended or on-going innovation activities)	% of enterprises	2012	2016
(c)	Percentage of the ICT sector in GDP	% GDP	2011	2017
(d)	Enterprises having received orders online (at least 1%)	% of enterprises	2011	2019
(e)	Enterprises that have ERP software packages to share information between different functional areas	% of enterprises	2012	2019
(f)	Enterprises using CRM to analyse information about clients for marketing purposes	% of enterprises	2010	2019
(g)	3D printing and robotics	% of enterprises	-	2018
(h)	Enterprises that employ ICT specialists	% of enterprises	2012	2019
(i)	Internet use: interaction with public authorities (last 12 months)	% of individuals	2011	2019
(j)	Big data analysis	% of enterprises	-	2018

Source: Eurostat and Worldbank database

Table 4: Components of Industry 4.0 relative performance index

STATE	Code country	(a)		(b)		(c)		(d)		(e)		(f)		(g)	
Austria	AT*	25.4	25.7	54.4	62.0	3.3	3.5	11.0	20.0	25.0	43.0	29.0	22.0	0.0	4.0
Belgium	BE*	20.8	19.1	55.9	68.1	4.1	3.7	22.0	30.0	40.0	53.0	28.0	25.0	0.0	6.0
Bulgaria	BG	25.6	23.8	27.4	27.2	4.6	5.7	3.0	7.0	11.0	23.0	10.0	11.0	0.0	2.0
Cyprus	CY	12.8	12.2	42.1	36.5	3.3	4.4	7.0	13.0	17.0	33.0	16.0	19.0	0.0	1.0
Czech Republic	CZ	33.4	32.2	43.9	46.3	4.4	4.4	26.0	29.0	21.0	38.0	10.0	15.0	0.0	4.0
Germany	DE*	27.1	27.5	66.9	63.7	4.0	4.2	20.0	18.0	29.0	29.0	23.0	20.0	0.0	5.0
Denmark	DK*	20.3	21.2	51.1	51.5	4.6	4.6	23.0	34.0	29.0	50.0	18.0	23.0	0.0	6.0
Estonia	EE	25.5	24.1	47.6	47.7	5.0	5.1	11.0	18.0	7.0	26.0	9.0	16.0	0.0	2.0
Greece	EL*	13.7	15.3	52.3	57.7	2.1	1.9	6.0	9.0	36.0	38.0	18.0	16.0	0.0	2.0
Spain	ES*	22.1	20.0	33.6	36.9	3.4	3.2	11.0	19.0	22.0	43.0	20.0	24.0	0.0	3.0
Finland	FI*	25.0	24.5	52.6	64.8	4.3	5.4	17.0	23.0	28.0	43.0	27.0	26.0	0.0	7.0
France	FR*	18.0	16.9	53.4	57.7	4.1	4.3	11.0	16.0	24.0	48.0	15.0	15.0	0.0	4.0
Croatia	HR	22.3	20.4	37.9	48.0	4.1	4.4	18.0	22.0	15.0	26.0	11.0	10.0	0.0	3.0
Hungary	HU	25.2	25.4	32.5	29.0	6.0	6.0	10.0	13.0	8.0	14.0	7.0	7.0	0.0	2.0
Ireland	IE*	24.6	36.8	58.7	57.3	9.3	11.6	23.0	36.0	20.0	28.0	25.0	25.0	0.0	3.0
Italy	IT*	21.7	21.4	56.1	53.8	3.4	3.3	4.0	10.0	22.0	35.0	15.0	15.0	0.0	4.0
Lithuania	LT	28.0	25.5	32.9	50.5	2.4	3.0	21.0	24.0	11.0	48.0	12.0	24.0	0.0	4.0
Luxembourg	LU*	11.2	11.8	66.1	63.8	6.3	5.4	15.0	9.0	21.0	41.0	19.0	18.0	0.0	4.0
Latvia	LV	21.1	19.5	30.4	30.3	3.3	4.7	9.0	11.0	8.0	32.0	11.0	12.0	0.0	1.0
Malta	MT	16.8	12.1	51.1	33.9	9.0	8.7	16.0	23.0	18.0	32.0	20.0	25.0	0.0	6.0
Netherlands	NL*	20.1	17.9	51.4	59.7	4.5	4.7	19.0	22.0	22.0	48.0	16.0	26.0	0.0	5.0
Poland	PL	29.8	28.6	23.0	22.0	3.3	3.3	8.0	14.0	11.0	29.0	13.0	21.0	0.0	2.0
Portugal	PT*	19.3	19.2	54.6	66.9	3.3	3.3	16.0	16.0	26.0	42.0	15.0	17.0	0.0	4.0
Romania	RO	38.5	29.0	20.7	10.2	3.1	3.5	4.0	12.0	19.0	23.0	14.0	14.0	0.0	2.0
Sweden	SE*	23.6	22.6	55.9	54.2	6.3	6.3	24.0	31.0	35.0	37.0	24.0	21.0	0.0	5.0
Slovenia	SI	26.8	28.4	46.5	39.8	3.5	3.7	11.0	18.0	21.0	33.0	11.0	10.0	0.0	4.0
Slovak Republic	SK	31.1	30.1	34.0	30.7	4.5	4.3	13.0	12.0	17.0	31.0	25.0	15.0	0.0	3.0
United Kingdom	UK*	18.7	17.5	50.3	58.7	5.4	6.0	15.0	25.0	6.0	24.0	13.0	17.0	0.0	6.0

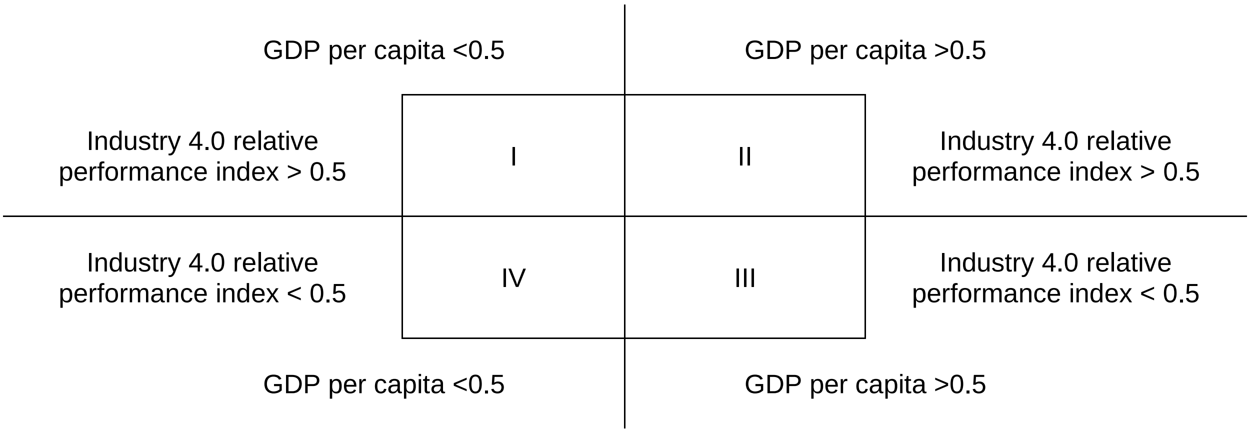
Source: Eurostat and Worldbank database

(*) EU15 – member countries in the European Union prior to the accession of ten candidate countries on 1 May 2004. The EU15 c
Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal,

In the first step of the analysis, components of the Industry 4.0 relative performance index (i.e. “secondary indicators”) were calculated. In the second stage, the simple average of the secondary indicators was calculated, thus creating the Industry 4.0 relative performance index for each country. Computation of our own indicator for the Industry 4.0 relative performance index makes it possible to evaluate changes in the relative position of EU member states. Academic literature lacks evaluations of the change of the relative position of individual EU states over a longer period of time, and therefore the analysis was carried out for the years 2011 and 2019 (data from 2018 and 2017 was also used according to availability when necessary).

The calculation of the Industry 4.0 relative performance index makes it possible to place EU members states into clusters. Cluster analysis is a method for the evaluation of multi-dimensional data while searching for groups whose members are as similar as possible while being as different from other members of the group as possible. For the means of this study, member states have been divided into 4 corridors that create clusters according to values of the Industry 4.0 relative performance index and GDP per capita (relative performance); these corridors are depicted in Figure 2. The combination of these two categories determines a country‘s relative position. The horizontal axis represents the traditional economic performance measure – GDP per capita.

Figure 2: Overview of the division of EU states into the Industry 4.0 relative performance index and GDP per Capita



Source: own research

Corridor I includes member states that have values of Industry 4.0 relative performance index that are higher or equal to 0.5, but the value of GDP per capita is <0.5. Corridor II includes countries that have values of Industry 4.0 relative performance index that are over 0.5 and a value of GDP per capita of ≥0.5. Corridor III includes member states that have values of Industry 4.0 relative performance index that are lower than 0.5 and have a value of GDP per capita of ≥0.5. Corridor IV includes countries that have values of Industry 4.0 relative performance index that are less than 0.5 and the value of GDP per capita is <0.5. We can expect that EU15 states will likely be located in Corridor II, as these are states with a relatively high GDP per capita and a good basis for the development of Industry 4.0. New member states are likely to be located in Corridor IV; nonetheless, we can assume a shift to Corridor I or, in the case of strong expansion, even to Corridor II. Berger (2015) divides states into 4 categories: (i) potentialists, (ii) frontrunners, (iii) traditionalists and (iv) hesitators. The division of these groups is relatively close to the division into corridors I-IV and the relative position of these groups can be compared in time.

Results

Table 5 shows the calculated values of the Industry 4.0 relative performance index (score) for the 2011 and 2019. The table also shows the order of states in individual years and the change in order between 2011 and 2019. According to Berger (2015), the frontrunners are: Germany, Ireland, Switzerland, Austria, Finland and Sweden. These results partially correspond to the results of the Industry 4.0 relative performance index. From the perspective of the Industry 4.0 relative performance index, leaders include Ireland, Denmark and Finland. In 2011, Sweden was in first place, but it did not hold this position and fell to 7th place. Germany also decreased in ranking, as it was first at 6th place and in 2019 fell to 10th. So-called "up-and-coming" countries include Lithuania, which moved up 11 places in the ranking from 24th to 11th place. Lithuania is rapidly developing its position as a global digital economy, which has been advanced by the growth in the proportion of innovative enterprises (see indicator b). According to the study by Berger (2015), Lithuania together with the Czech Republic, Slovak Republic, Hungary and Slovenia belong to the group of traditionalists, which still thrive on their sound industrial base, but few have thus far launched initiatives to take industry into the next era. Despite this fact, the Czech Republic did not unfortunately hold its position in 2011 and fell from the 9th position to the 12th, and thus together with Lithuania is one of the states that is shifting industry into the next area. The Czech Republic has relatively low values in several Industry 4.0 key indicators, such as: enterprises using CRM to analyse information about clients for marketing purposes and big data analysis; on the contrary, the Czech Republic has a relatively good standing in terms of the size of its share of industry in the economy and enterprises having received orders online.

Table 5: Industry 4.0 relative performance index

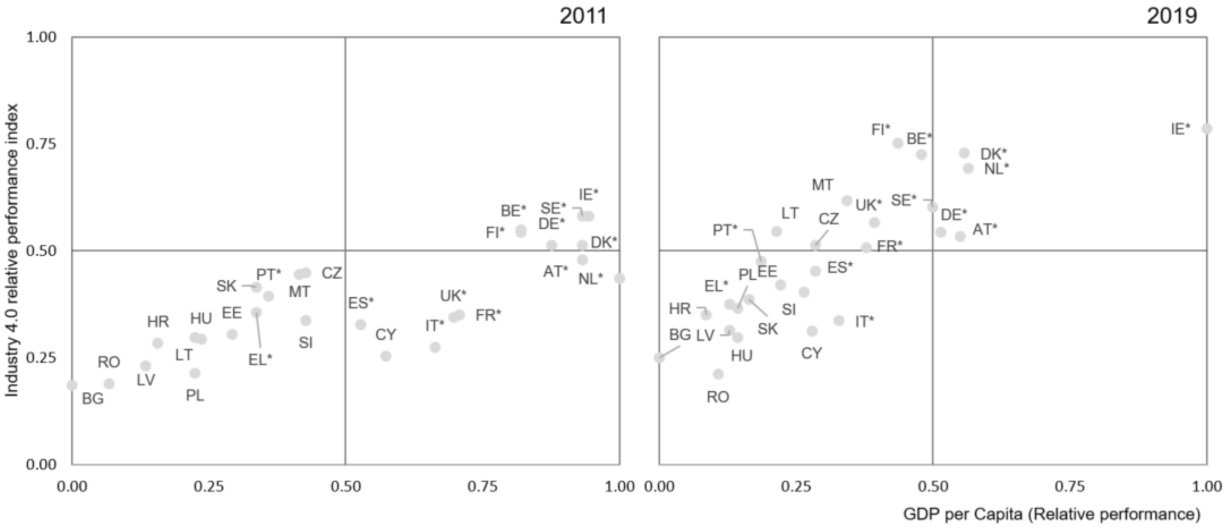
STATE	Code country	Score 2011	Rank 2011	Score 2019	Rank 2019	Change Rank 2019 vs. 2011
Austria	AT*	0.48	7	0.53	11	-4
Belgium	BE*	0.55	3	0.73	4	-1
Bulgaria	BG	0.18	28	0.25	27	1
Cyprus	CY	0.25	24	0.31	25	-1
Czech Republic	CZ	0.45	9	0.51	12	-3
Germany	DE*	0.51	6	0.54	10	-4
Denmark	DK*	0.51	5	0.73	3	2
Estonia	EE	0.30	19	0.42	17	2
Greece	EL*	0.36	14	0.38	20	-6
Spain	ES*	0.33	18	0.45	16	2
Finland	FI*	0.54	4	0.75	2	2
France	FR*	0.35	15	0.51	13	2
Croatia	HR	0.28	22	0.35	22	0
Hungary	HU	0.29	21	0.30	26	-5
Ireland	IE*	0.58	2	0.79	1	1
Italy	IT*	0.27	23	0.34	23	0
Lithuania	LT	0.30	20	0.55	9	11
Luxembourg	LU*	0.47	8	0.50	14	-6
Latvia	LV	0.23	25	0.31	24	1
Malta	MT	0.44	10	0.62	6	4
Netherlands	NL*	0.44	11	0.69	5	6
Poland	PL	0.21	26	0.37	21	5

STATE	Code country	Score	Rank	Score	Rank	Change Rank 2019 vs. 2011
		2011		2019		
Portugal	PT*	0.39	13	0.48	15	-2
Romania	RO	0.19	27	0.21	28	-1
Sweden	SE*	0.58	1	0.60	7	-6
Slovenia	SI	0.34	17	0.40	18	-1
Slovak Republic	SK	0.42	12	0.39	19	-7
United Kingdom	UK*	0.35	16	0.57	8	8

Source: Eurostat and Worldbank database, own calculation

For a better depiction of the relative position of member states, graphs have been created and are shown in Figure 3.

Figure 3: Cluster Division



Source: Eurostat and Worldbank database, own calculation

Note: In regard to the extreme GDP per capita value, the observation of Luxemburg was left out of the cluster analysis.

It is evident that in 2011 member states were located in Corridors II-IV and, as expected, a large portion of EU 15 member states was located in Corridor II. In 2019, the situation changed, as Corridor III was left empty and some states regrouped, specifically to Corridor I. This change is primarily due to the strengthening position of Ireland as a leader among EU member states and heightening displays of Industry 4.0 such as big data analyses and 3D print. Both graphs show a positive linear dependency between the Industry 4.0 relative performance index and overall economic performance. For member states that are located in Corridor IV and according to Berger (2015) can be labeled hesitators, Industry 4.0 has a strong but probably still unused potential for heightening their economic performance. This unused potential could be a signal for targeting support for the Industry 4.0 field, thus strengthening the EU economy as a whole in the future.

Conclusion

The concept of Industry 4.0 is a highly topical issue, primarily in the context of digitalization and the use of ICT. From an EU perspective, it is necessary to follow and report on how EU countries stand in implementing and using new technologies, the digitalization of enterprise processes, and processes on the level of public administrations, and also to follow and evaluate the possible impacts of the concept of Industry 4.0. It is evident that the studied concept will bring with it many positive factors, but will also have negative impacts primarily on the labor market and selected jobs.

Individual countries must accept and support the application of new trends both on the national and enterprise level and evaluate both economic and social impacts in time.

With respect to the significance of the given topic, the authors have focused on the evaluation or measurement of Industry 4.0 performance. The fact that the used indicators were very limited, simplified, or – in the case of composite indicators – lacking evaluations over a longer time period or links to other research carried out in this area was crucial for the application section of this paper. The authors thus decided to establish the following goal for the paper: create their own composite indicator based on findings of existing indicators for the measurement of Industry 4.0 and carry out a cluster analysis for EU countries.

There is a relatively large amount of academic studies in the area of the measurement of Industry 4.0 that focus on the composite indicators that attempt to capture this phenomenon statistically. At the moment, however, there are no available timelines of these composite indicators. In the empirical section, we have created our own indicator – the “Industry 4.0 relative performance index”. This Index was computed using the methodology of the World Economic Forum. Computation of our own composite indicator has made it possible to record the development of Industry 4.0 performance in time and thus evaluate the relative positions of member states. Cluster analysis was carried out for the years 2011 and 2019, and data was extracted from Eurostat and Worldbank statistics. The relative positions of EU countries were established, categorization into clusters was carried out, and development over time was recorded. The relative position of individual states between 2011 and 2019 changed; in Ireland’s case, its leading position was solidified while, on the contrary, Sweden and Germany moved farther down the ladder. The Czech Republic and Lithuania were evaluated as so-called “traditionalists” (Berger 2015) and it is evident in 2019 that they are closer to states labeled as “frontrunners”. For member states that are located in Corridor IV and can be labeled hesitators, Industry 4.0 has a strong but probably still unused potential for heightening their economic performance.

This completed research may naturally contain certain discrepancies that stem from the nature of composite indicators and results may thus be influenced by the selection of components. Components were selected based on the authors’ experience in order to provide the best statistical measurement of the studied phenomenon. However, it is clear that the statistical reporting of the Industry 4.0 phenomenon and phenomena related to it is a highly complex issue that deserves deeper research. This includes the context of timelines and the use of more advanced methods of cluster analysis.

Results of this completed research may serve as guidance for future targeting of cohesive EU policy in the field of Industry 4.0 support, which in the future may contribute to strengthening the position of the EU’s economy as a whole.

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References

Almada-Lobo, F. (2015). The Industry 4.0 revolution and the future of Manufacturing Execution Systems (MES). *Journal of innovation management*, *3*(4), 16-21. https://doi.org/10.24840/2183-0606_003.004_0003

Atik, H., & Ünlü, F. (2019). The Measurement of Industry 4.0 Performance through Industry 4.0 Index: An Empirical Investigation for Turkey and European Countries. *Procedia Computer Science*, *158*, 852-860. https://doi.org/10.1016/j.procs.2019.09.123

Berger, R. (2015). *Industry 4.0 - The role of Switzerland within an European manufacturing revolution.* Think Act March, Zurich.

Buguin, J., Dibbs, R., Bisson, P., & Marrs, A. (2013). *Disruptive technologies: Advances that will transform life, business, and the global economy.* McKinsey Global Institute: San Francisco, CA, USA.

Dutton, H. W. 2014. Putting Things to Work: Social and Policy Challenges for the Internet of *Things. Info*, 16(3), 1-21. https://doi.org/10.1108/info-09-2013-0047.

European Commision. (2018). Digital Transformation Scoreboard. Retrieved from:

European Commision. (2019). The Digital Economy and Society Index (DESI). Retrieved from: https://ec.europa.eu/digital-single-market/en/desi

European Commission. (2017). *Industry in Europe. Facts & figures on competitiveness & innovation 2017.* European Commision: Brusel.

Eurostat. (2020). Digital economy and society statistica. Retrived from: https://ec.europa.eu/eurostat/statistics-explained/index.php/Digital_economy_and_society_statistics_-_enterprises.

Frey, C., & Osborne, M. (2013). The Future of Employment: How suspectible are jobs to computeristation? Oxford: Martin School. Retrieved from: http://goo.gl/PgsTcO

Greengard, S. (2016).*The Internet of Things*. The MIT Press Essential Knowledge Series, USA.

https://ec.europa.eu/growth/tools-databases/dem/monitor/scoreboard

Chmelař, A. et al. (2015). *Dopady digitalizace na trh práce v ČR a EU*. Oddělení strategie a trendů Evropské unie (OSTEU). Retrieved from: https://www.vlada.cz/assets/evropske-zalezitosti/analyzy-EU/Dopady-digitalizace-na-trh-prace-CR-a-EU.pdf

Kagermann, H., & Wahlster, W. (2014). *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Final Report of the Industrie 4.0 Working Group.* Munich: National Academy for Science and Engineering.

Klímová, V., & Žítek, V. (2015). Inovační paradox v Česku: ekonomická teorie a politická realita. *Politická ekonomie*, *63*(2), 147-166. https://doi.org/10.18267/j.polek.994

Kovács, G., & Kot, S. (2016). New logistics and production trends as the effect of global economy changes. *Polish Journal of Management Studies, 14,* 115-126. https://doi.org/10.17512/pjms.2016.14.2.11

Morrar, R., Arman, H., & Mousa, S. (2017). The fourth industrial revolution (Industry 4.0): A social innovation perspective. *Technology Innovation Management Review, 7*(11), 12-20. https://doi.org/10.22215/timreview/1117

Mráček, K. (2017). Průmysl 4.0 – příležitost pro aplikovaný výzkum. AVO. Retrieved from: https://avobloguje.wordpress.com/2017/06/01/prumysl-4-0-prilezitost-pro-aplikovany-vyzkum/

Müller, K. (2017). Inovace-vědění-instituce: k výzvám současné doby. Charles University in Prague, Karolinum Press.

Pan, M., Sikorski, J., Kastner, C. A., Akroyd, J., Mosbach, S., Lau, R., & Kraft, M. (2015). Applying Industry 4.0 to the Jurong Island Eco-Industrial Park. *Energy Procedia, 75,*1536-1541. https://doi.org/10.1016/j.egypro.2015.07.313

Perakovič, D., Periša, M., & Zorić, P. (2019). Challenges and Issues of ICT in Industry 4.0. *Advances in Design, Simulation and Manufacturing II.,* 259-269, doi:.org/10.1007/978-3-030-22365-6_26.

Piccarozzi, M., Aquilani, B., & Gatti, C. (2018). Industry 4.0 in Management Studies: A Systematic Literature Review. *Sustainability, 10*, 3821. https://doi.org/10.3390/su10103821

Portulans Institute. (2019). The Network Readiness Index 2019: Towards a Future-Ready SocietyRetrieved from: https://networkreadinessindex.org/wp-content/uploads/2020/03/The-Network-Readiness-Index-2019-New-version-March-2020.pdf

PwC. (2017). *Industry 4.0: The Current State of Play in Flemish Manufacturing. Press Release.* from: https://www.pwc.be/en/news-publications/press/2017/industry4-0-the-current-state-of-play-in-flemish-manufacturing.html

Santos, C., Mehrsai, A., Barros, A. C., Araújo, M., & Ares, E. (2017). Towards Industry 4.0: an overview of European strategic roadmaps. *Procedia Manufacturing*, *13*, 972-979. https://doi.org/10.1016/j.promfg.2017.09.093

Schlechtendahl, J., Keinert, M., Kretschmer, F., Lechler, A., & Verl, A. (2015). Making existing production systems Industry 4.0-ready. *Production Engineering*, *9*(1), 143-148. https://doi.org/10.1007/s11740-014-0586-3

Schwab, K. (2016A). *The Fourth Industrial Revolution: what it means, how to respond.* Retrieved from: https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/#

Schwab, K. (2016B). *The Fourth Industrial Revolution.* World Economic Forum: Geneva, Switzerland.

Sommer, L. (2015). Industrial revolution - industry 4.0: Are German manufacturing SMEs the first victims of this revolution? *Journal of Industrial Engineering and Management, 8*(5), 1512-1532, doi:http://dx.doi.org/10.3926/jiem.1470.

Tomek, G., & Vávrová, V. (2017). *Průmysl 4.0 aneb Nikdo sám nevyhraje.* Praha: Professsional publishing.

World Bank. (2020). National accounts data. Retrieved from: https://data.worldbank.org/indicator/NV.IND.TOTL.ZS

Xu, L. D., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. *International Journal of Production Research*, *56*(8), 2941-2962. https://doi.org/10.1080/00207543.2018.1444806