ANALYSIS OF RELATIONSHIPS BETWEEN INNOVATIVE AND DIGITAL PERFORMANCE OF EU-27 COUNTRIES

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ABSTRACT. Background: The global digital economy is developing quickly, and innovation plays a crucial role in today's economic growth. **Aims:** The main aim was to investigate the interrelationships between the digital and innovation performance of the EU countries using the selected global indices (DESI, GII, SII). The main aim was fulfilled by 2 partial goals and subsequently set 2 hypotheses. **Methods:** To verify the hypotheses, we used the Kendall Tau coefficient (τ), panel data regression analysis and through this analysis, we created 3 models. **Sample:** We have chosen the EU-27 countries for our analyses. The length of the analyzed period was 5 years (2016-2020). **Results:** To select the resulting model from the 3 proposed models (Model 1 (OLS), Model 2 (FEM), and Model 3 (REM)), test criteria such as F-test, Breusch-Pagan test, and Hausman test were used. We consider Model 2 to be the most suitable model, which is the result of the Fixed Effects Model (FEM). **Conclusions:** The results of our analyses confirmed that a higher statistically significant positive relationship was identified between the digital performance of the EU-27 countries and their innovation performance evaluated using the SII versus the innovation performance using the GII.

Keywords: digital performance, innovation performance, panel data regression analysis, EU-27 countries

JEL Classification: O39, O40

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Introduction

The global digital economy is developing quickly. This has a significant impact on various areas of the economy (Rosario & Cruz, 2019), (Ghezzi & Cavallo, 2020). The expansion of digitization in several countries is one of the strongest current trends that are shaping today's global economy. The digitization of processes itself is driven by a strong assumption of achieving higher overall organizational performance (Kotarba, 2017) and building competitive advantages for both organizations and countries, and is important for the survival and growth of the economy.

Pan et al. (2022) claim that the digital economy has a multidisciplinary character, while the driving source of digitization is the use of information and communication technologies (ICT). Thus, the digital economy becomes a new economic form, which is influenced by the rapid development of industry and ICT. The technological changes that have emerged since the industrial revolution represent the driving force behind economic development. In this, we can find a similarity with the development of the digital economy.

Innovation plays a crucial role in determining today's economic growth patterns. In a fast - globalized world and with global competition, countries and enterprises that renew the range of their products and services take the lead (Hamidi & Berrado, 2018). Innovative activity is an important source of competitiveness, economic growth, as well as the image of each country. It is perceived to be a source of competitiveness and economic growth. New products, utility models, trademarks and creative projects are an important element of the present socio-economic reality. There are several ways to measure and evaluate the innovation performance of a country (Janoskova & Kral, 2019). In order for innovations to be properly directed and managed, they need to be measured and quantified (Hamidi & Berrado, 2018). It is quite difficult to measure the innovative activity of a country, which consists of several different areas that affect innovation performance. Two well-known ways to measure and evaluate the innovation performance of a country are the Global Innovation Index (GII) and the Summary Innovation Index (SII) (Janoskova & Kral, 2019).

The main aim was to investigate the interrelationships between the digital and innovation performance of the EU-27 countries using selected global indices (DESI, GII, SII) for the period 2016 to 2020. The originality of this study lies precisely in the combination of the mentioned three indices. To compare and analyze EU-27 data in all three indices at once is unique. From the sources that we have studied, it is clear, that the authors focus on one of the indexes, or on a combination of the selected index and another indicator. However, a summary comparison of all 3 digital and innovation indices at once was missing.

Theoretical background

Description of digital and innovation indices of countries

The competitiveness of the European economy depends on a knowledge-based economy and support for research and development (R&D). While the former is closely linked to human capital development and qualitative improvement, R&D activities presuppose the integration and development of information and communication technologies (ICT). One of the main initiatives of the EU 2020 strategy is the Digital Agenda for Europe. To achieve the targets quickly and on schedule, the proposed governance framework is based on an improved Digital Economy and Society Index (DESI). The DESI report tracks the progress made by EU member countries with respect to their digitization (Bánhidi, Dobos, & Nemeslaki, 2020) since 2014.

The Digital Economy and Society Index (DESI) is a composite index published annually by the European Commission since 2014. It measures the progress made by EU Member States in the digital economy and society, combining a set of relevant indicators (DESI, 2022).

DESI monitors the overall European digital performance and tracks the progress of EU countries in their digital competitiveness. The published reports also include profiles of individual countries, while a detailed chapter on telecommunications is added to the report on each member state. DESI country reports are a combination of quantitative data obtained according to DESI indicators in four areas as part of an index and an overview of policies and best practices in individual countries (Ministry of Investments, Regional Development and Informatization of the Slovak Republic, 2021). In 2021, the EC revised the DESI structure, replacing the previous five-dimensional structure with four main areas (Kovacs et al., 2022).

DESI is a widely used and cited measurement system by practitioners and policy makers, but it has some advantages and serious limitations. Disadvantages can also be viewed from a certain angle as advantages. The fact, that the index evaluates data for EU countries means, that the methodology is universal and applicable to everyone. For this reason, the results are also general and not suitable for in-depth analysis and explanation of certain phenomena. Another disadvantage is the often-changing selection of factors, changing the number of dimensions. The composition and number of dimensions change from year to year, making it difficult to compare the performance of time series. Also, the long period between data collection and publication leads to outdated assessments and conclusions. Regardless of the problems, the DESI collection method and system is still a robust approach that cannot be avoided in many cases and is considered the best choice for mapping Europe's digitization progress (Bánhidi, Dobos, & Nemeslaki, 2020).

The Digital Economy and Society Index (DESI) summarises indicators of Europe's digital performance and tracks the progress of EU countries. The DESI has a three-level structure with 4 dimensions, 10 sub-dimensions, and 33 indicators.

Table 1. Composition of the Digital Economy and Society Index (DESI)

Digital Economy and Society Index			
Human Capital	**Connectivity**	**Integration of digital technology**	**Digital public services**
▪ Internet User Skills (*dimension 1*) ▪ Advanced Skills and Development (*dimension 2*)	▪ Fixed broadband take-up (*dimension 3*) ▪ Fixed broadband coverage (*dimension 4*) ▪ Mobile broadband (*dimension 5*) ▪ Broadband price index (*dimension 6*)	▪ Digital intensity (*dimension 7*) ▪ Digital technologies for businesses (*dimension 8*) ▪ e-Commerce (*dimension 9*)	▪ e-Government (*dimension 10*)

Source: *own processing by European Commission (2021a)*

The background for the concept of innovation can be found in the writings of Schumpeter in the 1930s. Innovation has been perceived as a key driving force for economic growth. It also provides a response to many societal, technological, and business challenges. Innovation inputs cover a wide range of factors including, stable macroeconomic conditions, the availability of internal and external finance, expansion in public research, reduction of anti-competitive regulations, tax incentives, and openness to foreign R&D. Similarly, innovation outputs can be defined by different elements that can be perceived as the result of innovation within an economy (e.g., number of patents, number of trademarks, the share of sales in innovative products) (Jankowska, Matysek-Jędrych, & Mroczek-Dąbrowska, 2017).

There is a positive trend in the political determination across the globe to foster innovation and related policies on the ground. A few years ago, innovation and innovation policies related to high-income economies. Today, developed and developing economies have placed innovation on their agenda to boost economic and social development. Regardless of the economic and geopolitical uncertainties over the last few years, innovations seem to be blossoming globally (Dutta, Lanvin, & Wunsch-Vincent, 2019). As a result of this trend, the measure of innovation and its impact have been the main area of interest of various institutions.

We decided to analyse the area of innovation performance using two global indexes, the Global Innovation Index (GII) and the Summary Innovation Index (SII).

The **Global Innovation Index (GII**) is one of the impulses to the latest global innovation trends. This index observes the innovation capability and efficiency levels of individual countries using input and output factors (Sohn, Kim, & Jeon, 2016). GII report is a useful and rich dataset for comparing innovation efficiency and identifying innovation trends at both the national and global levels (Jankowska, Matysek-Jędrych, & Mroczek-Dąbrowska, 2017).

It annually evaluates the performance of the innovation ecosystems of economies around the world, while highlighting the strengths and weaknesses of innovation and specific gaps in innovation metrics. The index aims to capture the most complete picture of innovation and contains approximately 80 indicators, including measures of each economy's political environment, education, infrastructure, and knowledge creation. The various metrics offered by the GII can be used to monitor performance and compare developments against economies within the same region or income group classification (WIPO, 2021). However, it does not consider potential structural relationships among factors affecting the innovation performance of a country (Sohn, Kim, & Jeon, 2016).

Table 2. Composition of the Global Innovation Index (GII)

Global Innovation Index	
Input subindex	Output subindex
▪ Institutions (dimension 1) ▪ Human capital and research (dimension 2) ▪ Infrastructure (dimension 3) ▪ Market sophistication (dimension 4) ▪ Business sophistication (dimension 5)	▪ Knowledge and technology outputs (dimension 6) ▪ Creative outputs (dimension 7)

Source: *own processing by Cornel University, INSEAD & WIPO (2020)*

The Summary Innovation Index (SII) is a composite indicator aimed at evaluating innovation performance, which is processed as part of the European Innovation Scoreboards (EIS) project for the European Commission, Directorate-General for the Internal Market, Industry, Entrepreneurship and SMEs and is published from 2001 (EIS, 2022).

The EIS provides a comparative analysis of innovation performance in EU countries, other European countries, and regional neighbors. It assesses the relative strengths and weaknesses of national innovation systems and helps countries identify areas they need to address (European Commission, 2021a). The SII is used for analyzing the level of innovative ability of European countries (Kuklyte, 2017), (Edquist & Zabala-Iturriagagoitia, 2015). As an EU initiative, the Innovation Union monitors and periodically reports on the progress achieved in research, development, and innovations (Janoskova & Kral, 2019).

The Summary Innovation Index consists of four areas of assessment, namely Framework conditions, Investments, Innovation Activities, and Impacts. These areas contain ten innovation subgroups and consist of 32 indicators.

Table 3. Composition of the Summary Innovation Index (SII)

Summary Innovation Index			
Framework conditions	**Investments**	**Innovation activities**	**Impacts**
▪ Human resources (*dimension 1*)	▪ Finance and support (*dimension 4*)	▪ Innovators (*dimension 7*)	▪ Employment impacts (*dimension 10*)
▪ Research systems (*dimension 2*)	▪ Firm investments (*dimension 5*)	▪ Linkages (*dimension 8*)	▪ Sales impacts (*dimension 11*)
▪ Digitalisation (*dimension 3*)	▪ Information technologies (*dimension 6*)	▪ Intellectual assets (*dimension 9*)	▪ Environmental sustainability (*dimension 12*)

Source: *own processing by Hollanders a Es-Sadki (2021)*

Methodology

The main aim was to investigate the interrelationships between the digital and innovation performance of the EU-27 countries using selected global indices (DESI, GII, SII) for the period 2016 to 2020.

We have chosen countries of the European Union for our analyses. These countries currently form a group of 27 countries, and the length of the time period (5 years) was influenced by the availability of secondary data.

We obtained secondary data from the annual reports published by the European Commission (DESI and SII index) and WIPO (GII index) for the years 2017 to 2021. Considering, that the data entered for the evaluation of the analyzed indices are often from the previous year than the year of publication annual report, we decided to mark the analyzed period as 2016 to 2020.

The main goal was fulfilled by 2 partial goals, which were set in a logical sequence as follows:

- partial objective 1 → to analyse the development of the EU-27 countries using selected global indices (DESI, GII, and SII) for the period 2016-2020,
- partial objective 2 → to identify the existence of mutual relations and connections between the total score and the dimensions of the selected global indices of the EU-27 countries,

For partial objective 2, we have defined the following hypotheses, which we verified using appropriate statistical tools.

H1: We assume the existence of statistically significant relationships between the DESI score and the dimensions of the GII and SII indices of the EU-27 countries for the period 2016-2020.

H2: There is a statistically significant influence of selected dimensions of the GII and SII indices on the total DESI score of the EU-27 countries.

DESI, GII, and SII indices consist of several dimensions, respectively indicators listed in them. In Table 4 we present the designation of the analysed dimensions of these indexes, including the designation under which they enter statistical verification.

Table 4. Structure of analyzed indexes

Index	Description structure of indexes	Source
Digital Economy and Society Index (*DESI*)	The Digital Economy and Society Index (DESI) summarises indicators on Europe's digital performance and tracks the progress of EU countries. The DESI has a three-level structure as 4 dimensions, 10 sub-dimensions and 33 indicators. Dimensions of DESI: ▪ Human capital (*DESI_D1*) ▪ Connectivity (*DESI_D2*) ▪ Integration of digital technology (*DESI_D3*) ▪ Digital public services (*DESI_D4*)	European Commission
Global Innovation Index (*GII*)	The Global Innovation Index (GII) ranks world economies according to their innovation capabilities. The GII aims to capture the multi-dimensional facets of innovation. Consisting of 80 indicators, grouped into innovation inputs (5 dimensions) and outputs (2 dimensions). Dimensions of GII: ▪ Institutions (*GII_D1*) ▪ Human capital and research (*GII_D2*) ▪ Infrastructure (*GII_D3*) ▪ Market sophistication (*GII_D4*) ▪ Business sophistication (*GII_D5*) ▪ Knowledge and technology outputs (*GII_D6*) ▪ Creative outputs (*GII_D7*)	WIPO
Summary Innovation Index (*SII*)	Summary Innovation Index (SII) are data from the European Innovation Scoreboard that provides a comparative assessment of the research and innovation performance of EU Member States and selected third countries. Dimensions of SII: ▪ Human resources (*SII_D1*) ▪ Research systems (*SII_D2*) ▪ Digitalisation (*SII_D3*) ▪ Finance and support (*SII_D4*) ▪ Firm investments (*SII_D5*) ▪ Information technologies (*SII_D6*) ▪ Innovators (*SII_D7*) ▪ Linkages (*SII_D8*) ▪ Intellectual assets (*SII_D9*) ▪ Employment impacts (*SII_D10*) ▪ Sales impacts (*SII_D11*) ▪ Environmental sustainability (*SII_D12*)	European Commission

Source: *own processing from annual reports of European Commission (2021a, 2021b, 2021c), WIPO (2021)*

The results of the descriptive statistics of the analysed indices of digital and innovation performance of the EU-27 countries for the period 2016 to 2020 are presented in Table 5.

Table 5. The results of descriptive statistics

Variable	Mean	Median	Min	Max	Lower	Upper	Range	Quartile	Std.Dev.	Skewness	Kurtosis
DESI	40.5130	40.5181	19.3991	65.2503	33.4378	47.0231	45.8512	13.5853	9.5611	0.1207	-0.3093
GII	48.3014	47.8300	35.6000	63.8000	42.0500	54.2000	28.2000	12.1500	7.3915	0.3489	-0.8160
SII	46.2066	43.9536	15.4279	73.1306	33.6920	61.3492	57.7027	27.6573	15.2219	-0.0926	-1.0833

Source: *own processing*

To verify the hypotheses, we used the Kendall Tau coefficient (τ) and panel data regression analysis.

The value of the Kendall Tau (τ) coefficient was calculated as follows:

$$\tau = \frac{2\sum_{1\le i<j\le n}\sum_{1\le i<j\le n} a_{i,j}}{\left(n(n-1)\right)} \quad (1)$$

The Kendall τ coefficient is interpreted in a way like the previous cases. The coefficient is defined in a closed interval from −1 to 1, where values closer to ± 1 represent a stronger association (Lyócsa, Baumöhl, & Výrost, 2013, p. 182-183).

Panel data combines cross-sectional and time data. For panel data, there is a time sequence for each entity used in the cross-sectional selection. Panel data is most often used to examine the time evolution of different units from the same sector, market, or geographical unit, with a typical large cross-sectional structure and only a few time periods.

Panel regression models include the following types of models according to Lukáčiková, Lukáčiková, and Szomolányi (2008):

- *Pooled Regression (OLS)* – if the individual effect is only a vector of units, which means that a single parameter α is a common constant:
  $y_{it} = \alpha + \beta_1 x_{it1} + \beta_2 x_{it2} + \ldots + \beta_k x_{itk} + u_{it}$ (2)
- *Fixed Effects Model (FEM)* – if individual effects Z_1 to Z_q are unobservable but correlate with explanatory variables, then the solution is to include all effects in the estimating conditional average using the relation $\alpha_i = \alpha_1 z_{i1} + \alpha_2 z_{i2} + \ldots + \alpha_q z_{iq}$ while the model FEM is as follows:
  $y_{it} = \alpha_i + \beta_1 x_{it1} + \beta_2 x_{it2} + \ldots + \beta_k x_{itk} + u_{it}$ (3)
  – fixed effect αi means a specific constant for each cross-sectional unit.
- *Random Effects Model (REM)* – if individual effects Z_1 to Z_q are unobservable and to not correlate with explanatory variables, then the solution is the compound random variable $\varepsilon_i + u_{it}$, which, in addition to the original, also assumes a specific random component for each cross-sectional unit, while the REM model is as follows:
  $y_{it} = \beta_1 x_{it1} + \beta_2 x_{it2} + \ldots + \beta_k x_{itk} + (\alpha + \varepsilon_i) + u_{it}$ (4)

Results and discussions

The first goal was to analyze the development of the EU-27 countries using selected global indices (DESI, GII and SII) for the period 2016-2020, which we decided to implement in 2 levels, namely:

- analysis of the average score of selected indices of the EU-27 countries for the years 2016-2020,
- analysis of the development trend of the average total score of the DESI, GII and SII indices and their dimensions of the EU-27 countries for the individual years 2016 to 2020.

Figure 1 presents the results of the average score of DESI (brown colour), GII (blue colour) and SII (green colour) for the period 2016 – 2020.

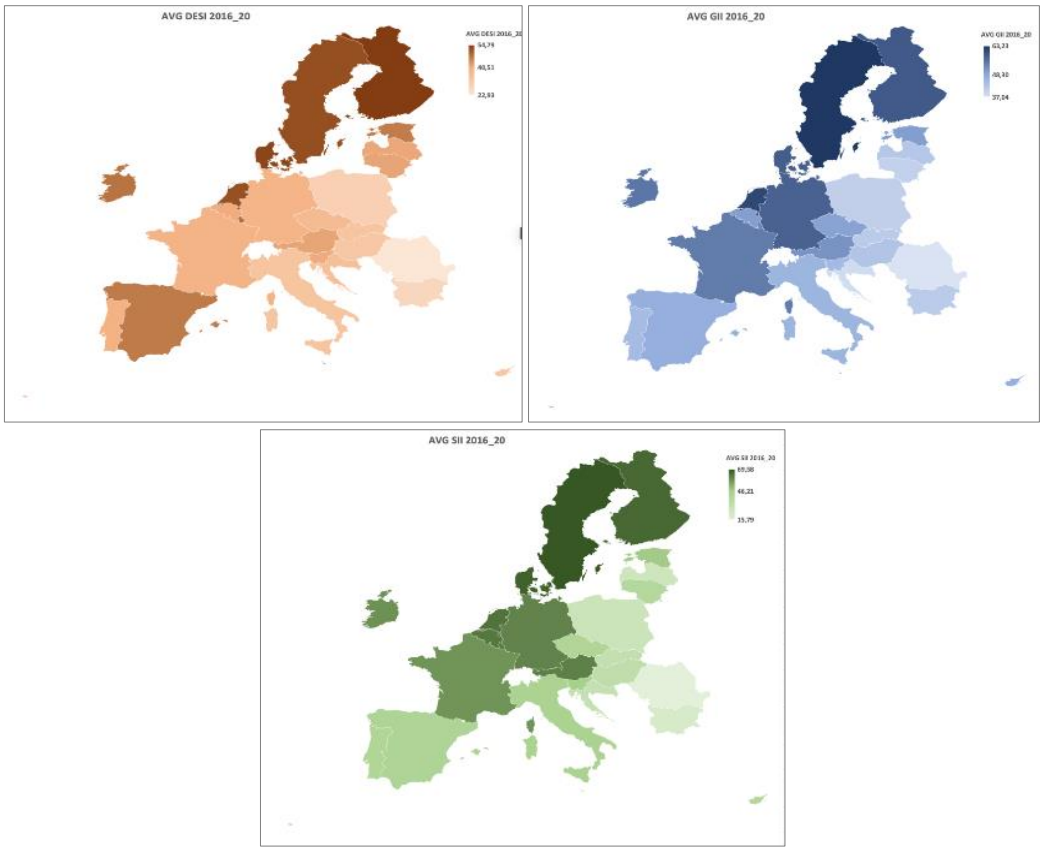

Figure 1. Average scores of DESI, GII and SII of EU-27 countries for 2016 - 2020
Source: *own processing*

When evaluating the average score of the analysed indices, we can state that the Nordic countries are among the leaders, as same as in the study of Kovács et al. (2022), Kinnunen, Androniceanu, and Georgescu (2019) and Androniceanu et al. (2019). Finland (DESI=57.79) and Sweden can be considered the leader in the evaluation of innovation performance (GII=63.23, and SII=69.58). On the contrary, the worst results in the evaluation of all global indices were achieved by Romania (DESI=22.93, GII=37.04 and SII=15.79). In this respect, we obtained similar results to Stoian and Nica (2016). The GII_{EU-27} index had the best average European score at 48.30, followed by SII_{EU-27} with an average score of 46.21, and the $DESI_{EU-27}$ digital performance index (40.51) achieved the lowest values.

In the following analysis, we focused our attention on the analysis of the development of the overall score of the DESI, GII, and SII indices of the EU-27 countries according to the individual analysed years, the results of which are presented in Figure 2.

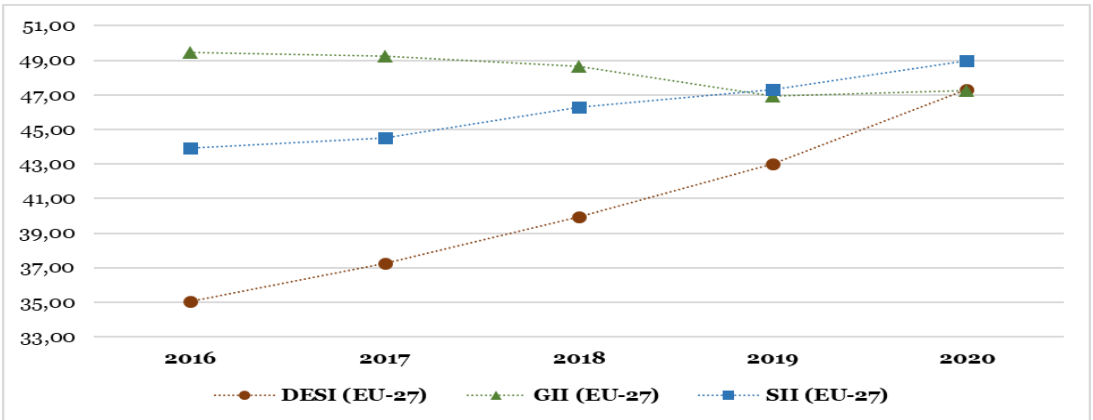

Figure 2. Comparison of the development of EU-27 indices for the years 2016-2020
Source: *own processing*

From Figure 2 we can see that the fastest growth rate is visible for the DESI index (EU-27), which reached a height of 35.07 in 2016, but in 2020 its overall score increased by almost 35%. We also noticed a very similar development trend for the SII index, while its total score increased by 11.5% and reached the highest total score of 48.96 compared to the other analysed indices in 2020. A different course of development is evident for the GII index, whose total score gradually decreased and reached its lowest value in 2019 (46.93). In 2020, the GII index decreased by 4.4% compared to 2016. In 2020, they achieved very similar overall scores for the 2 analysed indices, namely the DESI index (47.34) and the GII index (47.26).

The results of a mutual comparison of the development of the total score as well as the dimensions of the analysed indices of European Union countries for the individual years 2016 to 2020 are shown in the following Figure 3, 4 and 5.

The development of the scores of the 4 dimensions of the DESI index has a growing trend, as does the overall score of the analysed index. In this regard, we can find similar conclusions to the conclusions of Banhidi, Dobos, and Nemeslaki (2020) and Stavytskyy, Kharlamova, and Stoica (2019), who also showed an increasing trend, providing on older data. So, this trend continues even in the newer analysed years. The exception is the evaluation of dimension 1 – Human capital, where the values range from 10.84 to 11.75 and thus, we did not notice significant changes as for the other dimensions.

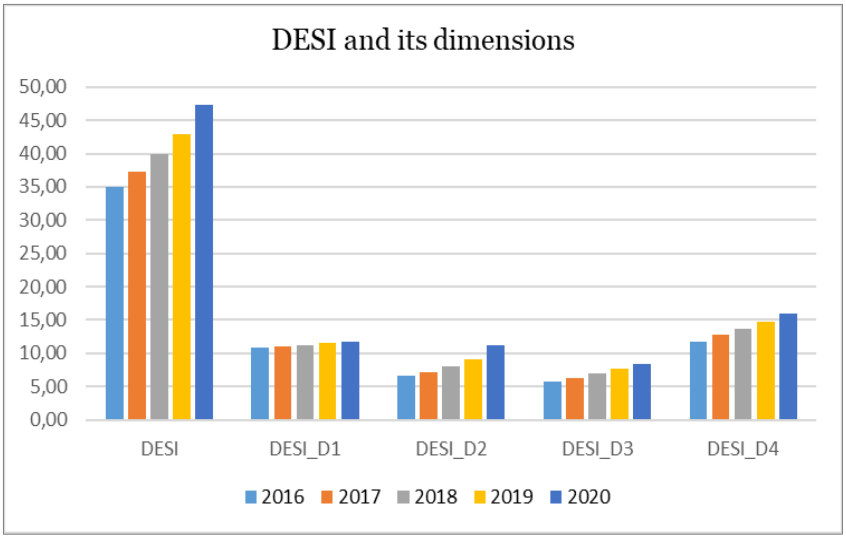

Figure 3. Development of average DESI score and its dimensions of EU-27countries
Source: *own processing*

The second analysed index is the GII index, while the development of the scores of individual dimensions has a slightly fluctuating trend, except for dimension 7 – Creative outputs. This dimension was the only one that gradually decreased from the value of 46.86 in 2016 until 2019, where it reached a score of 37.94, but in 2020 we saw its increase to the level of 39.38. The highest rated dimension of the GII index was dimension 1 - Institutions, whose score was around 79.

The last analysed index is the SII index, which consists of up to 12 dimensions, and the individual dimensions developed in a positive direction, except for dimension 9- Intellectual assets, whose score gradually was falling. The most significant positive change occurred in the evaluation of dimension 7 – Innovators, which grew by more than 26% year-on-year over the last two analysed years. The highest score of the SII index dimension is visible for dimension 3 – Digitalisation, whose value reached its maximum at 63.72. The lowest rated dimension of the SII index was dimension 5 – Firm investments, which in 2016 reached a height of only 38.29. In this regard, it is interesting to see different conclusions, and how the development over time changes the position of individual dimensions. Even though the study of Janoskova and Kral (2019) was processed until 2016, the sample of countries (V4) is similar, even though in our case there are more countries (27). Janoskova and Kral (2019) demonstrated that dimension 5 - Firm investments was evaluated among others in the given period as one of the best in the V4 sample. On the contrary, the weakest results were in the Innovation dimension.

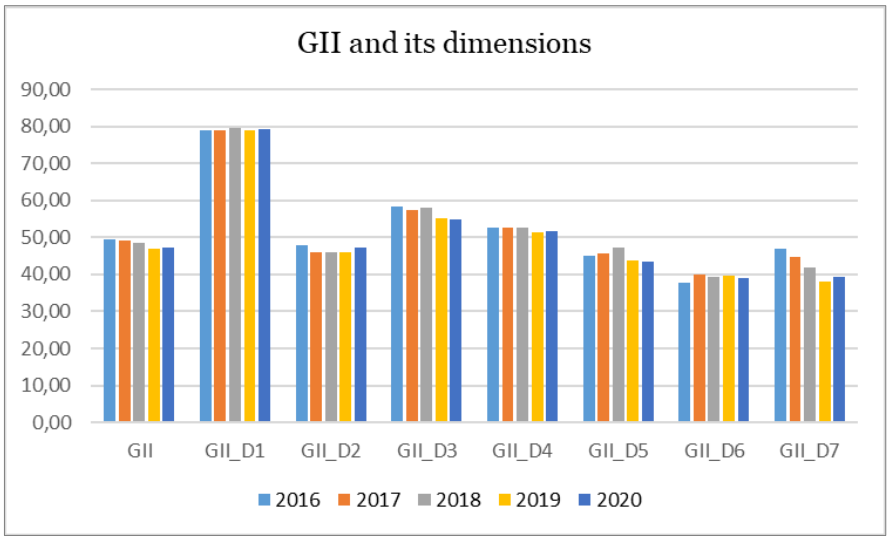

Figure 4. Development of average GII score and its dimensions of EU-27countries
Source: *own processing*

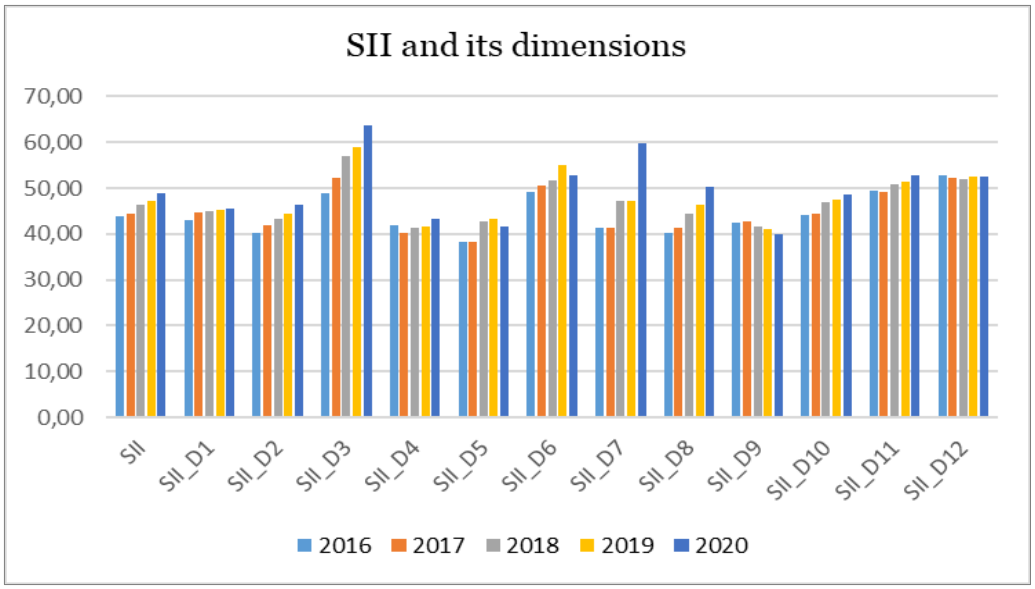

Figure 5. Development of average SII and its dimensions of EU-27countries
Source: *own processing*

At the end of the analysis of the digital performance of the EU-27 countries for the period 2016 to 2020, we can state that the digital leaders are the Nordic countries - Finland, Denmark, and Sweden, while Finland was the leader in the years 2016-2019 and in 2020 it was replaced in this position by Denmark. Romania was always in the last place in the digital ranking and Greece, Bulgaria, and Poland were in front of it during the entire analysed period. Here we can also see a similarity with the conclusions of Stavytskyy, Kharlamova, and Stoica (2019), while their analysis confirmed that a more prosperous society leads to more advanced digital services. Even though the mentioned research was carried out until 2018, certain features in the conclusions adopted at that time can be seen in the development in the following years.

The study of Kovács et al. (2022) also points out to similar results as ours, for the period 2016-2021. The difference is that Kovács et al (2022) only analysed the data on the digital readiness of EU citizens from DESI, and in our case the entire DESI index was analysed.

The results of the study made by Androniceanu, Georgescu, and Kinnunen (2019) also confirm our results, that Nordic countries obtain the highest values of DESI and the lowest were in Bulgaria and Romania. The mentioned authors analysed the EU countries for 2018, which is only one year, while in this study we considered a period of up to 5 years. Another common feature with the authors is the fact, that the entire DESI index was analysed, not just a part of it. But it remains an interesting fact, that

Nordic countries were in the second cluster and Romania and Bulgaria in the third cluster by k-means algorithm during the cluster analysis by Androniceanu, Georgescu, and Kinnunen (2019).

We evaluated the innovation performance of selected European countries using two indices - GII and SII. We can unequivocally consider Sweden as an innovation leader, which was ranked 1st in both rankings, except for 2017, when the Netherlands was in the first position. Nordic countries such as Denmark, Finland, and the Netherlands belongs again to this group. The weakest analysed European Union country is Romania, which in the evaluation of innovation performance was in the last position during the analysed 5 years within both indexes. Based on the achieved results of the GII index, countries such as Greece and Croatia were placed at the bottom of the ranking ahead of Romania, and for the SII index, the unfavourable position belongs to countries such as Bulgaria, Latvia, and Poland.

The digital performance of Slovakia gradually decreases during the analysed period, until it was ranked 20th in 2016 and 2017, during the next 2 years it moved 1 place lower, and in 2020 it is the 22nd position in the DESI index. When looking at the results of innovation performance, Slovakia's position is almost at the same level as when evaluating digital performance within the EU-27 countries. A slightly better rating was achieved by Slovakia for the GII index, where its performance hovers around the 21st place, the rating through the SII index assigned the 22nd position, which worsen by 1 place downwards in 2020.

In partial objective 2, we tried to identify the existence of mutual relations and connections between the total score and the dimensions of selected global indices of the EU-27 countries for the period 2016-2020.

We established 2 hypotheses, which we verified using appropriate statistical tools. To verify H1, we applied the non-parametric Kendall Tau coefficient, which we chose based on the results of normality testing for the input secondary data. Normality was verified using three statistical tests such as the Kolmogorov-Smirnov test, the Liliefors test, and the Shapiro-Wilk test, and the results confirmed that several analyzed indices do not have a normal distribution.

The results of the performed correlation analysis are presented in Table 6. We can state, that at the level of significance $\alpha = 5\%$, Kendall Tau reached only positive values in the range from 0.1746 to 0.7045, thus confirming the positive relationship between the DESI index and the GII and SII indices and their dimensions. Between the DESI index and the GII index, a moderate positive correlation relationship ($\tau_{DESI\&GII}=0.4465$) and a largely positive relationship of the SII index ($\tau_{DESI\&SII}=0.5748$) was confirmed according to Cohen's scale. We found the highest Kendall Tau value between the DESI index and dimension 3 - Digitalization of the SII index ($\tau_{DESI\&SII\_D3}=0.7045$), and on the other hand, the lowest value was between the DESI index and dimension 11 - Sales impacts of the SII index ($\tau_{DESI\&SII\_D11}=0.1746$).

Table 6. Results of correlation analysis between DESI and GII and SII indices

Kendall Tau Correlations DESI GII SII 2016-2020; MD pairwise deleted Marked correlations are significant at p <.05							
Pair of Variables (N=135)	Kendall Tau	Z	p-value	Pair of Variables	Kendall Tau	Z	p-value
DESI & GII	0.4465	7.6821	< 0.001	DESI & SII	0.5748	9.8894	< 0.001
DESI & GII_D1	0.5239	9.0142	< 0.001	DESI & SII_D1	0.5473	9.4170	< 0.001
DESI & GII_D2	0.3459	5.9514	< 0.001	DESI & SII_D2	0.4959	8.5313	< 0.001
DESI & GII_D3	0.3364	5.7878	< 0.001	DESI & SII_D3	0.7045	12.1206	< 0.001
DESI & GII_D4	0.3488	6.0015	< 0.001	DESI & SII_D4	0.4465	7.6814	< 0.001
DESI & GII_D5	0.4409	7.5860	< 0.001	DESI & SII_D5	0.2783	4.7877	< 0.001
DESI & GII_D6	0.3227	5.5523	< 0.001	DESI & SII_D6	0.5391	9.2750	< 0.001
DESI & GII_D7	0.3237	5.5692	< 0.001	DESI & SII_D7	0.3220	5.5398	< 0.001
				DESI & SII_D8	0.5060	8.7063	< 0.001
				DESI & SII_D9	0.4056	6.9791	< 0.001
				DESI & SII_D10	0.4199	7.2251	< 0.001
				DESI & SII_D11	0.1746	3.0035	0.0027
				DESI & SII_D12	0.2767	4.7611	< 0.001

Source: *own processing in STATISTICA version 13*

At the end of this section, we can conclude, that when verifying H1, a statistically significant relationship between the digital performance represented by the DESI index and the innovation performance measured by the GII and SII indices of the EU-27 countries for the period 2016-2020 was found by correlation analysis at the level of significance $\alpha = 5\%$, which leads to rejection of the null hypothesis about the non-existence of dependence between the DESI index and the GII and SII indices and their dimensions.

Based on these results, we can assume, that the SII index dimensions will prevail in the analysis revealing statistically significant effects of selected dimensions of the GII and SII indices on the total

DESI score. To verify the influence of the dimensions of the GII and SII indices on the total score of the DESI index of the EU-27 countries, we used panel data regression analysis, which we implemented using OLS, FEM, and REM models.

When creating models through panel regression analysis, we estimated the following proposed models:

Model 1 : $DESI_{OLS} = f(GII\_D1, \ldots GII\_D7, SII\_D1, \ldots SII\_D12)$ (5)
Model 2 : $DESI_{FEM} = f(GII\_D1, \ldots GII\_D7, SII\_D1, \ldots SII\_D12)$ (6)
Model 3 : $DESI_{REM} = f(GII\_D1, \ldots GII\_D7, SII\_D1, \ldots SII\_D12)$ (7)

A total of 19 independent variables were involved in creating the regression models, which represented the dimensions of the selected innovation indices of the EU-27 countries for the period 2016-2020, while 7 dimensions were from the GII index and 12 dimensions were from the SII index. The results of our research shown in Table 7 indicate that the proposed panel regression analysis models achieved very similar results.

Table 7. Results of panel data regression analysis

	Model 1 (OLS)			**Model 2 (FEM)**			**Model 3 (REM)**		
	Coefficient	*p-value*		*Coefficient*	*p-value*		*Coefficient*	*p-value*	
const	16.3664	0.0656	*	15.5453	0.0871	*	16.1677	0.0672	*
GII_D1	0.1452	0.3112		0.16218	0.2754		0.1493	0.2986	
GII_D2	**−0.2149**	**0.0042**	***	**−0.2082**	**0.0064**	***	**−0.2131**	**0.0039**	***
GII_D3	−0.1248	0.2095		−0.1341	0.1891		−0.1273	0.1997	
GII_D4	0.0677	0.4084		0.0673	0.4323		0.0678	0.4096	
GII_D5	−0.1401	0.1229		−0.1281	0.1676		−0.1371	0.1297	
GII_D6	0.1192	0.0899	*	0.1105	0.1233		0.1170	0.0943	*
GII_D7	**−0.1827**	**0.0112**	**	**−0.1756**	**0.0176**	**	**−0.1808**	**0.0112**	**
SII_D1	**13.5885**	**0.0009**	***	**12.63**	**0.0030**	***	**13.3958**	**0.0010**	***
SII_D2	**−17.6059**	**0.0002**	***	**−16.8691**	**0.0006**	***	**−17.4114**	**0.0002**	***
SII_D3	**36.3676**	**<0.0001**	***	**37.1086**	**<0.0001**	***	**36.5422**	**<0.0001**	***
SII_D4	**7.2209**	**0.0178**	**	6.4022	0.0503	*	**7.0062**	**0.0220**	**
SII_D5	**−12.0624**	**0.0006**	***	**−11.8806**	**0.0010**	***	**−12.0102**	**0.0005**	***
SII_D6	**10.0600**	**0.0040**	***	**10.8600**	**0.0076**	***	**10.6400**	**0.0039**	***
SII_D7	0.3214	0.9380		0.2345	0.9550		0.3016	0.9417	
SII_D8	2.1881	0.5699		1.6347	0.7171		2.0681	0.6035	
SII_D9	4.4901	0.2100		4.7016	0.2112		4.5550	0.2052	
SII_D10	**15.9522**	**0.0364**	**	**15.5639**	**0.0462**	**	**15.8384**	**0.0362**	**
SII_D11	−0.4809	0.9006		−0.2666	0.9455		−0.4217	0.9127	
SII_D12	**5.4332**	**0.0494**	**	4.6908	0.1123		5.2400	0.0595	*

*Note: * p<0.10; ** p<0.05; *** p<0.01*
Source: *own processing in GRETL*

For the established hypothesis H2, using panel data regression analysis, a statistically significant influence between the total score of the DESI index and selected dimensions of the GII and SII indices for the EU-27 countries for the years 2016 to 2020 was confirmed at the level of statistical significance p<0.01;0.05;0.1, which leads *to rejecting the null hypothesis of the absence of mutual influence between DESI and the dimensions of the GII and SII indices*.

In Table 8, we present the results of the panel regression analysis, where only those dimensions of the analysed innovation indices are listed, for which the regression coefficients were confirmed at the α = 1% significance level.

Table 8. Final results of panel data regression analysis

Variables	**The name of the index dimension**	**Model 1 (OLS)**	**Model 2 (FEM)**	**Model 3 (REM)**
GII_D2	Human capital ad research	−0.2149	**−0.2082**	−0.2131
SII_D1	Human resources	13.5885	**12.6300**	13.3958
SII_D2	Research systems	−17.6059	**−16.8691**	−17.4114
SII_D3	Digitalisation	36.3676	**37.1086**	36.5422
SII_D5	Firm investments	−12.0624	**−11.8806**	−12.0102
SII_D6	Information technologies	10.0600	**10.8600**	10.6400

Note: p<0.01
Source: *own processing in GRETL*

To select the resulting model from the 3 proposed models (Model 1 (OLS), Model 2 (FEM), and Model 3 (REM)), test criteria such as F-test, Breusch-Pagan test, and Hausman test were used. We consider Model 2 to be the most suitable model, which is the result of the Fixed Effects Model (FEM).

Model 2 : $DESI_{FEM} = -0.2082GII\_D2 + 12.63SII\_D1 - 16,8691SII\_D2 + 37.1086SII\_D3 - 11,8806SII\_D5 + 10.86SII\_D6$ (8)

Model 2 (***DESI$_{FEM}$***) consists of 6 dimensions out of a total of 19 dimensions, that have a statistically significant impact on the overall digital performance score (DESI) of the EU-27 countries for the years 2016 to 2020. This model is made out from one dimension of the GII (*D2 - Human capital and Research*) and five dimensions of the SII index (*D1 – Human resources, D2 – Research systems, D3 – Digitalisation, D5 – Firm investments, D6 – Information technologies*). By comparing the independent variables in the regression model, we can conclude, that the DESI indicator was significantly determined by three variables (SII_D1, SII_D3, and SII_D6) with a positive impact, while the highest impact was recorded for the dimension focused on digitalisation (SII_D3), followed by the impact of human resources (SII_D1) and information technologies (SII_D6). On the other hand, in the proposed regression model (Model 2) there are 3 independent variables that negatively affect the digital performance of the EU-27 countries. The variable Research systems (SII_D2), then the variable Firm investments (SII_D5), and the variable GII_D2, which represents Human capital and research, had the most significant negative impact on the digital performance of the EU-27 countries.

In the end, we can conclude, that despite the fact, that we managed to create a regression model affecting the digital performance of the EU-27 countries using selected dimensions of innovation performance measured by the GII and SII indices, it is necessary to continue the research in the future. Further research direction should be focused on individual indicators that are input variables for evaluating the innovation performance of the EU-27 countries, and the analysis of these independent variables can reveal important positive or negative effects on increasing the digital performance of the countries of the European area or the world on a larger scale.

Conclusion

The results of our analyses confirmed that a higher statistically significant positive relationship was confirmed between the digital performance of the EU-27 countries and their innovation performance evaluated using the SII ($\tau_{DESI\&SII}$=0.5748) versus the innovation performance of the EU-27 countries evaluated using the GII ($\tau_{DESI\&GII}$=0.4465). The results of our further analyses confirmed that the following independent variables had a statistically significant (positive or negative) impact on the assessment of the digital performance of the EU-27 countries during the years 2016 to 2020:

- digitalisation (SII_D3), human resources (SII_D1), and information technologies (SII_D6) have a positive impact on the evaluation of the digital performance of the EU-27 countries,
- we recorded a negative impact on the research system (SII_D2), firm investments (SII_D5), and human capital and research (GII_D2).

Of course, this research has some limitations. The initial limits are based on the methodologies of the individual indexes. On their composition and on the other hand, in the changes in the indicators and the methods of calculation. The sample of the countries can be considered as another limiting factor. Even though the countries are part of the EU-27, there are still significant differences between countries' level of the studied indices, innovation, and digital areas. The last limitation of this research also follows from this, namely, that there is a high probability of endogeneity problem when examining the impact (linkage).

The results obtained in this study are very interesting. For future research, it would be good to verify the mentioned relationships over a longer period. Because we can see that similar studies by other authors obtained sometimes similar results, even if they were performed during a different period.

Alternatively, it would also be possible to set up a similar study that would analyse countries all over the world using similar methods. But here comes the problem, not all the indices listed here also evaluate countries outside the EU. In this regard, it would be advisable to find a replacement for such indices and repeat the study with changed inputs and an expanded sample of countries.

It would be interesting if we could use and compare another model containing similar parameters as a subject for further investigation. However, while processing this article, we did not come across a similar model for EU countries.

In any case, innovation, digitization, and the subsequent growth of the country's competitiveness are broad issues subject to constant developmental changes. Increased interest in these

areas brings with it new knowledge, features, and relationships. And therefore, we cannot consider this study as our last in the given area.

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