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DIGITAL TRANSFORMATION AND ECONOMIC GROWTH – DESI IMPROVEMENT AND IMPLEMENTATION

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Abstract. The paper aims to improve the methodology of the Digital Economic and Society Index (DESI), the European Commission's newest index to assess the development of the digital economy. In particular, we investigate whether methodological changes to the structure of DESI improve its ability to capture the digital transformation of EU economies. Using the sensitivity-based analysis, we check whether the selection of weights of individual elements included in the DESI is optimal or should be improved.

We also verify the importance of DESI in explaining changes in GDP per capita in EU economies. In the literature, we find that digital transformation has enabled the creation of new business models and maximized efficiency in traditional firms. Using DESI, we empirically test whether the gap between rich and poor countries in European Union can be closed or eliminated through rapid and intensive digital transformation.

Our results show that the DESI – when modified by eliminating the pillars on internet services and digital public services – has the same explanatory power. Connectivity is the dimension with the largest impact on digital transformation in EU countries. We also find that DESI is a significant regressor to explain changes in GDP per capita in EU countries.

Keywords: composite indicators, digital transformation, DESI, economic growth, sensitivity analysis, European Union.

JEL Classification: O30, C18, F63.

Introduction

The paper concentrates on digital transformation measurement and the relationship between digital transformation and economic growth. Digital transformation means doing things in a new, digital way and is very closely connected with the digital revolution. The latter brings enormous opportunities and formidable challenges in the areas of the economy, innovation, education, health, governance, and lifestyles (Mühleisen, 2018). It has its roots in the

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1950s with the history-making invention of the transistor, but it did not truly blossom until the 1990s. Less than 1 per cent of technologically processed information worldwide was in digital format in the late 1980s, surpassing more than 99 per cent by 2012 (Hilbert, 2020). Moreover, humanity can store more knowledge every 2.5 to 3 years than before the beginning of civilization (United Nations Conference on Trade and Development [UNCTAD], 2019).

In the economy, the digital revolution begins on a large scale at the end of the 20th century, when the Internet was put into economic use. The positive effects of the digital economy can be seen on countless fronts. First of all, digitalization supports economic growth, but the power of influence depends on the research methodology applied in the study and geographical configuration (Molinari & Torres, 2018; Solomon & van Klyton, 2020). It also strongly changes the labour market structure by reducing the demand for routine work and low-skilled workers (Peetz, 2019). Additionally, digitalization transforms how businesses operate and connect with their customers and suppliers. It has a considerate impact on improving the effectiveness of business operations (Ritter & Pedersen, 2020).

The digital revolution also has a tremendous effect on society by revolutionizing how people interact and how governments interact with citizens through e-government platforms (Zhao et al., 2015). It improves the quality of life; the Eurobarometer (European Commission, 2017) results indicate that 76% of EU citizens using the Internet every day in 2017 say that the impact of these technologies on their quality of life has been positive. Digitalisation also boosts citizens' access to public services (Lindgren et al., 2019). The COVID pandemic demonstrated the importance of digitalization as digital tools allow essential services (e.g. access to medical care) to be provided or governments' mandatory actions such as lockdowns, vaccines, or hospital facilities to be coordinated (Kuc-Czarnecka, 2020; OECD, 2020a).

The digital revolution is underway and accelerates. The established metrics and assessment instruments cannot keep up with the rapid digital transformation pace (OECD, 2019a). The OECD (2019b) identifies many gaps in the current framework of measuring digital transformation and recommends improving the international comparability of the indicators currently in use. Also, a better adaptation of current statistical systems to rapid changes brought about by the digital revolution is strongly recommended.

The literature covers several indices used to assess the development of the digital economy, starting from the Information Society Index (1997), E-Readiness Index (2000), Technology Achievement Index (2001), E-Government Development Index (2002), ICT Development Index (2002), Networked Readiness Index (2002), Digital Access Index (2003), Knowledge Economy Index (2005), Digital Opportunity Index (2005), ICT Opportunity Index (2005), ICT Diffusion Index (2006), and ending up with the newest one – the Digital Economy and Society Index (2014). These measures propose a holistic framework for assessing the digital revolution's multi-faceted impact on society and economies. Our paper analyses the latest index, the Digital Economic and Society Index (DESI), proposed by the European Union. It is based on 37 individual indicators and evaluates the digital transformation of EU countries from the point of view of e-business, e-society and e-administration. So far, the DESI has been used to assess the degree of digital economy development in particular countries (Vidruska (2016) for Latvia; Moroz (2017) for Poland; Burlacioiu et al. (2018) for Romania; Nagy

(2019) for Hungary; Česnauskė (2019) for the Baltic countries; Kontolaimou and Skintzi (2018), and Laitsou et al. (2020) for Greece). To the best of our knowledge, the methodology proposed in the DESI has not been verified or attempted to be improved yet.

We wish to fill this gap, aiming to improve the DESI and investigating its relationship with economic growth. The paper examines whether methodological modifications to the DESI structure boost its ability to capture the digitalization of society and economies. We also consider whether the selection of weights of variables included in the DESI is optimal or could be improved. Additionally, we use panel data models to check if changes in the DESI influence EU economies' growth. The research questions that will be answered in this paper are: (1) can we improve the DESI as a composite indicator of the digital transformation of the EU-28? and (2) could the DESI be used as a GDP per capita forecast measure for the EU-28? To answer those research questions, we use data from the 2015–2020 DESI reports[1]. The novelty of the paper is the improvement proposal of the Digital Economic and Society Index to better assess the development of the digital economy, instead of creating a new index. New knowledge will be added by suggesting a new composition of the DESI that better reflects changes in the development of the digital economy. Additionally, our paper brings the novelty for the EU-28 policy decision-makers, i.e., providing a modified DESI as a new GDP per capita driver. We indicate that digitization has the potential to drive growth more sustainably and equitably, with innovation improving the well-being of citizens and supporting economic resilience. This was particularly evident in the wake of the COVID-19 pandemic, with its impact on everyday activities and economic interactions.

The remainder of the paper is organized as follows. Section 1 provides an overview of the DESI design and literature review on the relationship between the digitalization of the economy and its growth, development, and sustainability. Section 2 describes the applied methodology with particular emphasis on sensitivity analysis. Section 3 contains the results, and the last section concludes.

1. Digital Economy and Society Index – structure and relationship with economic growth

1.1. Digital transformation and economic growth

Digital transformation can be treated as the process related to technological changes, which almost occur in each economy and society. In economic theory, neoclassical theory (Solow), endogenous growth theory (Romer), and evolutionary growth theory (Freeman) all agree that technological change is a crucial factor in economic growth. In particular, endogenous growth theory emphasizes the role of technological change as an important driver of economic growth. For this reason, in empirical literature, we can find previous empirical analyses that suggest that digital transformation can be a powerful driver of growth.

Some research suggests that micro-level business efficiency is enhanced by digital transformation processes that drive economic growth. Innovative applications such as SMAC

[1] Each edition of the report is largely based on statistical data from the previous period. Thus, we are de facto analyzing digitization in the period 2014–2019.

(Social, Mobile, Analytics and Cloud) have increased the efficiency of production, sales and communication processes (Berman, 2012; Kotarba, 2018). Access to the Internet and the development of mobile applications allow companies to adapt more quickly to turbulent economic conditions, including new consumer expectations (Olszewska, 2020). For this reason, digital transformation is becoming an essential element of business development strategies (Bełz et al., 2019). Moreover, digital transformation occupies a crucial place in socio-economic development strategies, e.g. one of the six strategic priorities of the European Commission for 2019–2024 is linked to digital transformation, namely "A Europe fit for the digital age").

At the macro level, digital convergence positively affects growth, mainly by the labour productivity growth (Aly, 2020). Digital technologies are treated as a new production factor, which creates a new virtual workforce with higher productivity and efficiency and lower business process costs. However, the impact of digital transformation on individual countries and sectors is mixed. Developed economies benefit from higher economic growth, but emerging economies from job creation (Mićić, 2017). The main reason for the disparate impact of digital transformation lies in the economic structures of countries. Developed economies rely mainly on domestic consumption, making non-tradable sectors important. In contrast, in developed economies, digitization improves productivity and has a measurable impact on growth. Additionally, the digital transformation process is closely related to the macroeconomic concept of digital competitiveness, i.e., the ability of countries to implement and explore digital technology (IMD World Digital, 2020; Roszko-Wójtowicz & Grzelak, 2020, Małkowska et al., 2021). Digital competitiveness is gaining increasing attention as a source of competitive advantage and as a crucial element of national strategies to achieve economic growth and socio-economic development (Laitsou et al., 2020)

The literature also provides us with evidence on how strong the impact of digital transformation on economic growth is. Sabbagh et al. (2013) find that a ten percent increase in a country's level of digitalization boosts GDP per capita growth by 0.75%. This impact is much stronger if we consider only one aspect of digital transformation, namely the necessary infrastructure for a digital economy. According to Minges (2016) a 10 percentage point increase in fixed broadband penetration would boost GDP growth by 1.21% in developed countries and 1.38% in developing countries. In turn, McKinsey institute (2018) estimates a total contribution of new digital technologies to GDP, which ranges from 1.4% annually (for digital frontrunners) to 0.4% for "catch-up" countries. A digital transformation's positive effects on growth do not necessarily occur immediately. Park and Choi (2019) show that it takes time for digital transformation to impact economic growth in individual economies and for its effects to spill over across the economy.

Studies that have found a broadly positive relationship between digitization and economic growth use different measures of digitization (Deloitte, 2021). However, these studies have mostly focused on the impact of single digital indicators, such as measures of broadband penetration (Banerjee et al., 2020), mobile telephony (Toader et al., 2018), or internet usage (Myovella et al., 2020). These analyses may ignore the important role of changes in the broader digital system. Hence the idea of examine the relationship between a digital transformation and the economic growth by using composite index, which includes different aspects of digital transformation. For our analysis, we chose broader metric such as the EU's Digital Economy and Society Index (DESI).

Previous studies use DESI to examine the digital development of a given economy and make recommendations on aspects of the digital dimension that should be improved, e.g., for Hungary (Nagy, 2019); for Poland (Moroz, 2017); for Romania (Burlacioiu et al., 2018); for the Baltic countries (Česnauskė et al., 2019); and for Greece (Laitsou et al., 2020). Few studies use DESI for economic growth analysis. Stavytsky et al. (2019) examine whether DESI is correlated with a component of growth. They find that consumption and DESI are positively correlated, while unemployment has a negative impact. In turn, Vyshnevskyi et al. (2020) find that the level of digitization of the EU economy measured by DESI, does not have a decisive impact on the growth rate. In the latest report by Deloitte (2021), the authors find that a 10% increase in the DESI score is associated with a 0.65% increase in GDP per capita. In our study, we will first optimize DESI and then examine its impact on economic growth. We have included two hypotheses in the theoretical part of the paper, see Section 1. "Digital Economy and Society Index – structure and relationship with economic growth", the subsection "Digital transformation and economic growth". The hypotheses are as follows: (1) DESI's improvement, understood as weights coherence with variables importance can be achieved by reducing the set of variables and changing the weighting scheme and hypothesis; (2) Economic growth, measured by GDP per capita, can be well explained by both the original and optimized DESI.First, we want to describe DESI in detail and show how its dimensions are correlated with economic growth.

1.2. DESI – index structure

The European Commission (EU) announced a new Digital Economy and Society Index (DESI) in 2014 during the Digital4EU Stakeholder Forum in Brussels. The index aims to monitor 28 EU Member States' digital performance and measure their progress towards a digital economy and society. The DESI is a composite index that summarises several aspects of Europe's digital performance and monitors Member States' evolution in digital competitiveness. The EU creates DESI as part of Europe's Digital Scoreboard, the most vital EU tool to examine trends in the digital transformation of EU members. The Digital Economic and Society Index also aims to provide analytical support for introducing the Single Digital Market concept. The DESI covers five different dimensions of the digital economy (Figure 1).

The first dimension is connectivity, which means a necessary infrastructure for a digital economy and society. In the economic literature, the interest in connectivity is related to its

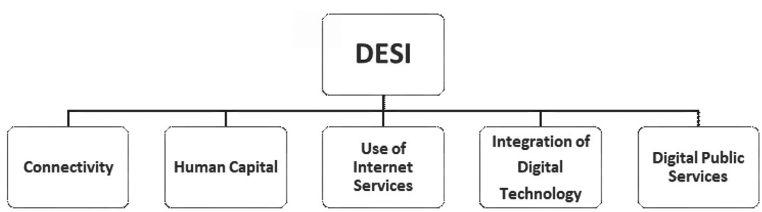


Figure 1. Five dimensions representing main policy areas in DESI

positive impact on economic growth (Kiseľáková et al., 2019). Many studies confirm that a high penetration of fixed and mobile broadband supports economic growth and, in some cases, employment and labour productivity (Arvin & Pradhan, 2014). Other researchers indicate a non-linear relationship between broadband penetration and GDP output (Minges, 2016). It appears that broadband penetration has only a marginal impact until a critical mass of users is achieved. After reaching this critical mass in connectivity, countries can generate GDP growth by increasing infrastructure quality. The analysis conducted by Rohman and Bohlin (2012) for 33 OECD countries, Briglauer and Gugler (2018) for 27 EU members, and by Katz and Callorda (2019) for 159 countries indicate a positive effect of broadband speed on GDP. Thus, the first dimension of the DESI includes indicators that measure digital infrastructure (see 1a1, Figure 2) and the quality of connectivity (e.g. 1a2, Figure 2).

Human capital is the second large dimension of the DESI. It consists of indicators referring to basic and advanced skills (Figure 3). The inclusion of indicators relating to human capital in the DESI aligns with resources and appropriation theory (Van Dijk, 2005; Van Dijk & Van Deursen, 2014; Bilan et al., 2020). It considers digital skills as a crucial part of the appropriation of ICTs. Basic skills are essential for people to manage their everyday activities in the digital society and include the use of Internet resources and information and communication management, carrying out digital transactions, use of government services, and online safekeeping. More advanced skills are essential for employees to adapt to the labour market changes, i.e., digitalization forces employees to possess high-level, non-routine cognitive skills (OECD, 2019c). The European Centre for the Development of Vocational Training (Cedefop, 2017) believes that 90% of Europe's vacancies will shortly require some digital knowledge. Digital skills seem to be a critical shortage in the development of a digitalized economy. According to the 2020 research conducted in the UK, the British economy

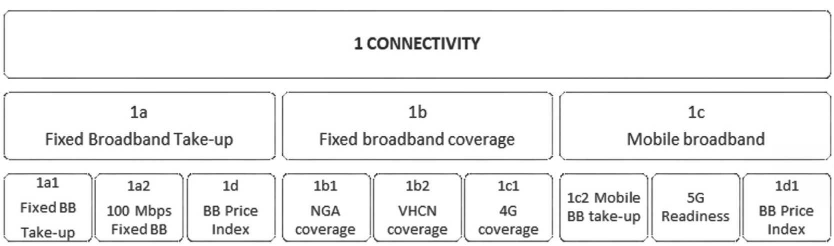


Figure 2. Connectivity indicators in DESI

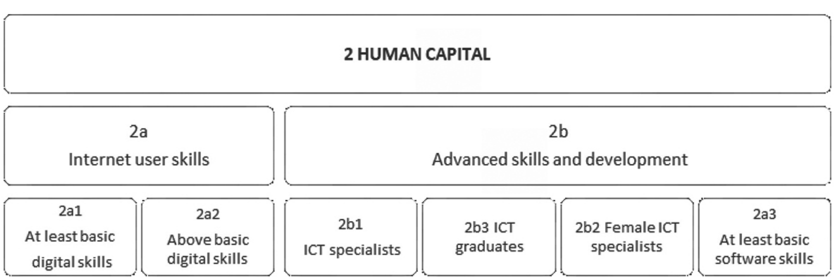


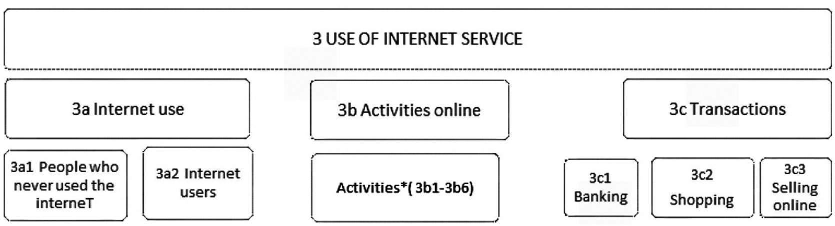
Figure 3. Human capital indicators – a part of DESI

could lose as much as £141.5 billion in GDP growth if it fails to close the gap in skills and help the next generation in training for a career that will eventually be online (Fenews, 2020).

The third main component of the DESI is the use of Internet services. Citizens are engaged in many activities online: they consume content such as news, music, movies, TV, or games. They communicate in different ways (e.g. via online video-calls, or social networks). They are engaged in transactions such as banking or shopping online (Figure 4). Such activities are drivers for the development of broadband networks.

The previous analysis shows that countries benefit in various ways from increased Internet usage. The extent of this effect depends on the country's income level, i.e. Internet use has a substantial positive impact on GDP per capita and overall welfare, mainly in low-income countries (Macdougald, 2011). Salahuddin and Gow (2016) argue that in low-income countries, the Internet use stimulates economic growth but only via a channel of financial development. In turn, Ejemeyovwi et al. (2019) find that Internet use in low-income economies has a significant and positive relationship with human development but not with economic growth. In developed countries, various studies indicate that the effect of growing Internet use on economic growth is minimal or even non-existent, producing mixed results (Cioacă et al., 2020).

The fourth dimension of the DESI is called "Integration of digital technology" and covers business digitalization, and e-commerce (see Figure 5). The factors driving digital transformation come from both the citizens' and businesses' sides, where solutions and models are implemented to a growing number of customers.



Note: *b1 – News; 3b2 – Music, videos and games; 3b3 – Video on demand; 3b4 – Video calls; 3b5 – Social networks; 3b6 – Doing an online course.

Figure 4. Use of Internet services indicators – a part of DESI

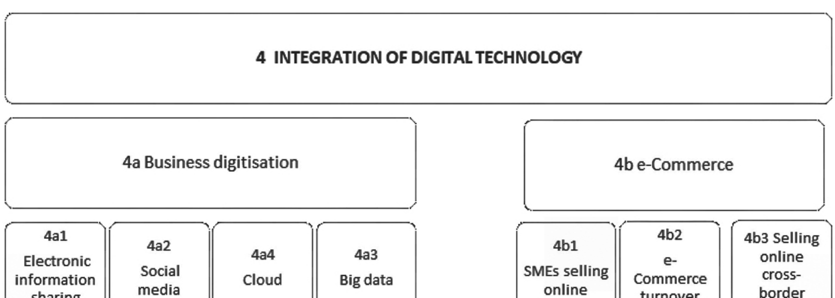


Figure 5. Indicators of dimension "Integration of digital technology"

The "Integration of digital technology" dimension includes two main subindicators: business digitalization and e-commerce. Business digitalization aims to allow automation, enhance data quality, and collect and structure information to implement advanced technologies such as better and more innovative apps. Higher process performance, lower transaction costs, and improved business processes are essential business digitalization benefits (Verhoef et al., 2021). According to Elding and Morris (2018), business digitalization boosts economic growth mainly through productivity growth. The more accessible it is to share knowledge within the company, the more efficient production processes are, and the easier acquiring knowledge from the outside is.

The second subindicator in this dimension is e-commerce, which is understood as the transmission of funds or data through the Internet to facilitate the purchase and sales of goods and services. It could impact economic growth via two main channels (Birlea & Capatina, 2017). The first one is productivity. Businesses and customers who use e-commerce save money by reducing the amount of time and effort to look for goods and complete transactions. As a result of lower costs, productivity improves (Kinda, 2019). The second channel is international trade. E-commerce promotes foreign trade by facilitating access to global markets without administrative barriers and lower transportation costs (Nassrullah Mzwri & Altinkaya, 2019).

The last dimension of the DESI includes indicators related to digital public services (Figure 6).

Digital technology can help companies and citizens communicate more effectively with the government, and governments will help meet citizens and businesses' needs (Aker, 2017). The impact of e-government on the economy is visible through enhanced service delivery and higher democratization (Spirakis et al., 2010), lower corruption levels (Máchová et al., 2018), as well as higher business competitiveness (Hoa & Pan, 2016). Some studies suggest that the development of digital public services is positively associated with economic growth due to reducing the time to generate and deliver services, the improvement of transparency in the public sector, and more accessible public information (Abdel Azim et al., 2020; Al-Refai, 2020; Osman, 2020). Srivastava and Panigrahi (2016) confirm a positive impact of e-government on gross domestic product per capita in a sample of developing countries, but not in the case of developed economies.

The DESI is the composite index, so all indicators are normalized, weighted, and aggregated[2]. Experts from the European Commission assign different weights to the five di-

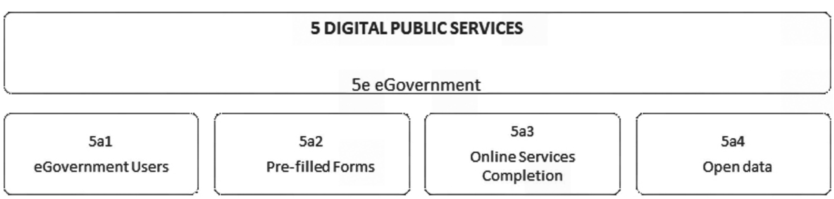


Figure 6. Indicators of digital public services in DESI

[2] A detailed description of all indicators is included in the report "DESI2020-Methodological Manual", https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi, pp. 5–9.

mensions to measure a member state's overall score. Connectivity and human capital each account for 25% of the overall score, integration of digital technology accounts for 20%, while online activities ("use of Internet services") and digital public services each account for 15%. Different weights are also assigned to subdimensions and individual indicators[3].

Most of the indicators from DESI come from Eurostat. Some broadband indicators are collected by the Commission services from Member States via Communications Committee. Other indicators, such as some e-government are based on data from studies carried out on behalf of the European Commission. The complete list of DESI components with data sources is available on the European Commission's website[4].

2. Methodology

The empirical analysis of this study was divided into two parts – investigating whether the weights given by the DESI creators correspond to the real meaning of the individual variables and testing whether the DESI can be used as a proxy of economic growth. Therefore, the methodological section also deals with two issues – improvement to composite indicators (CIs) using the sensitivity-based approach (SA) and the estimation of panel data models. The study used data from the 2015–2020 DESI reports (each edition is based on data from the previous year, European Commission, 2020a), maintaining their original composition. Hence, the United Kingdom is also included in the last year of the analysis. We decided to do this for two reasons. Firstly, the UK is still included in the report (it is not included since the 2021 edition). Secondly, to keep the fully balanced panels with the same number of observations. Thirdly, removing the UK from the list of analyzed objects would require recalculation of the original DESI (due to the normalization of variables) and could lead to changes in the initial ordering.

2.1. Sensitivity-based approach

The previous section describes the areas of the DESI and its relation to economic growth. However, one should be aware that for the composite measure to fulfil the function assigned to it by the creators, the weights of individual elements should reflect the real significance of each component. It is frequently the case that during the development of a composite indicator, the weighing stage is omitted, assuming tacitly equal weights for each factor or – just as often – non-equal weights are assigned arbitrarily. Unfortunately, both approaches are often biased (Saltelli, 2007; Gnaldi & Del Sarto, 2018; Greco et al., 2019; Cinelli et al., 2021). We apply a sensitivity-based approach (SA) to investigate the coherence of the measure with its methodology. The procedure that we applied is presented in Figure 7.

The DESI, as most composite indicators (CIs), is calculated as weighted arithmetic mean:

$$y_j = \sum_{i=1}^{d} w_i x_{ji}, \; j = 1,2,\ldots,n; \, i = 1,2,\ldots,d, \tag{1}$$

[3] The report "DESI2020-Methodological Manual" summarises the weights used at the subdimension stage. https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi, pp. 14–15.

[4] https://ec.europa.eu/digital-single-market/en/digital-economy-and-society-index-desi

where y_j – value of the CI for the j-th country, x_{ji} – normalized value of the i-th variable in the j-th country, w_i – weight assigned to the i-th variable.

To be more precise, the DESI formula is as follows (European Commission, 2020a):

$$\begin{aligned}&DESI(C) = Connectivity(C)\cdot 0.25 + Human\_capital(C)\cdot 0.25 +\\&Use\_of\_Internet\_Services(C)\cdot 0.15 +\\&Integration\_of\_Digital\_Technology(C)\cdot 0.2 +\\&Digital\_Public\_Services(C)\cdot 0.15.\end{aligned} \tag{2}$$

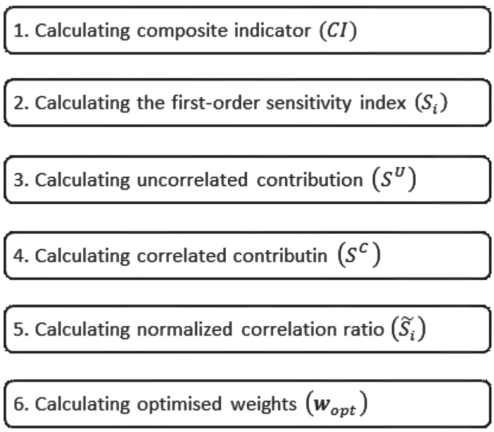


Figure 7. Procedure for verifying whether weights correspond to the actual significance

The impact of x_i on y may be determined and isolated by calculating the first-order sensitivity index (Saltelli et al., 2000, Saisana et al., 2005; Paruolo et al., 2013):

$$S_i \equiv \frac{V_{x_i}\left(E_{\boldsymbol{x}\sim i}\left(y \mid x_i\right)\right)}{V\left(y\right)}, \tag{3}$$

where S_i – first-order sensitivity measure, $S_i \in \left[0,1\right]$ (Saltelli & Tarantola, 2002), $\boldsymbol{x}_{\sim i}$ – vector containing all variables but x_i, $E_{\boldsymbol{x}\sim i}\left(y \mid x_i\right)$ – expected value of y at a given value of x_i with the expectation taken over $\boldsymbol{x}_{\sim i}$ – also known as the main effect of x_i, $V\left(y\right)$ – unconditional variance of y.

If the variables were uncorrelated, S_i would be the expected reduction of variance in the CI if a given indicator (x_i) could be fixed. Using S_i may invalidate creators' assumptions about (i) the equal importance of variables a and b if $S_a \neq S_b$, (ii) the greater importance of variable a than variable b if $S_b > S_a$. In this context, "importance" refers to the variable's correlation with the overall rank, thus if $S_i = 0$, the rank of the variable and CI rank are not associated, whereas if $S_i = 1$, then there is a perfect knowledge of indicator ranks. In our study, $E_{\boldsymbol{x}\sim i}\left(y \mid x_i\right)$, is estimated via a non-linear regression fit using penalized splines (Lindén et al., 2021), which allows us to perform the following decomposition:

$$S_i = S_i^u + S_i^c, \tag{4}$$

where S_i – first-order sensitivity measure, S_i^u – uncorrelated contribution, which is the unique variability that can only be explained by indicator x_i, S_i^c – correlated contribution, the variability caused by all variables associated with the indicator x_i.

This decomposition allows us to determine whether the variable's influence results from its correlation with other variables $\left(S_i^c \approx S_i\right)$ or whether x_i carries a sufficiently high information load in itself. When S_i is known, uncorrelated part S_i^u can be estimated by performing the multivariate linear regression of x_i on $\boldsymbol{x}_{\sim i}$ and finding the residuals:

$$\widehat{z_i} = x_i - \widehat{x_i} = x_i - \left(\beta_0 + \sum_{l \neq i}^{d} \widehat{\beta_l} x_i\right), \tag{5}$$

where $\widehat{z_i}$ – residuals of a regression of x_i on $\boldsymbol{x}_{\sim i}$, β_0 – y-intercept from multivariate linear regression, β_l – coefficient from multivariate linear regression. Next, the non-linear regression of y to $\widehat{z_i}$ fitted values is used to estimate S_i^u:

$$S_i^u = \frac{\sum_{j=1}^{n}\left(\hat{y}_j^{(\sim i)} - \overline{y}^{(\sim i)}\right)^2}{\sum_{j=1}^{n}\left(y_j - \overline{y}\right)^2}, \tag{6}$$

where S_i^u – uncorrelated contribution, $\hat{y}_j^{(\sim i)}$ – non-linear regression fitted values, $\overline{y}^{(\sim i)}$ – average value of $\hat{y}_j^{(\sim i)}$, y_j – composite indicator value in the j-th object, $\overline{y}$ – average value of y_j. When the uncorrelated part is known, it is easy to compute the correlated part S_i^c:

$$S_i^c = S_i - S_i^u. \tag{7}$$

If both uncorrelated (6) and correlated (7) contribution is known, it is possible to apply the optimization algorithm to adjust the weights:

$$\tilde{S}_i = \frac{S_i}{\sum_{i=1}^{n} S_i}, \tag{8}$$

where $\tilde{S}_i$ – normalized correlation ratio of x_i.

Thus, optimal weights can be computed as (Becker et al., 2017):

$$\boldsymbol{w}_{opt} = \operatorname{argmin}_w \sum_{i=1}^{d}\left(\tilde{S}_i^* - \tilde{S}_i(\boldsymbol{w})\right)^2, \tag{9}$$

where $\tilde{S}_i^*$ – target normalized correlation ratio, i.e. a situation in which initial weights reflect the intended importance of each indicator, $\boldsymbol{w}$ – set of weights $\boldsymbol{w} = \{w_i\}_{i=1}^{d}$. The optimization process in this study was carried out using the Nelder–Mead method (Nelder & Mead, 1965). The optimization algorithm relocates the weight to match the target correlation ratios, i.e., each indicator's intended relative importance. The optimal weights were selected so that they sum up to one and are non-negative.

2.2. Panel data models

The second part of our study concerns the impact of the DESI and its pillars on economic growth. Due to the short time series (the DESI has been published since 2015), it was impossible to test for the Granger causality, and we do not apply the dynamic panel data approach for the same reason. Thus, to verify the hypothesized impact of the DESI on other variables, we applied panel data regressions.

The starting point for the estimation was the following pool model:

$$y_{it} = \alpha + \sum_{i=1}^{n} \beta_j x_{jit} + u_{it}, \quad (10)$$

where y_{it} – dependent variable in the i-th country in year t, x_{ijt} – j-th independent variable in i-th country in year t, α – intercept, β_j – structural parameters, u_{it} – error term. At a later stage, we applied panel diagnostics tests – Breusch–Pagan and Hausman tests (Stock & Watson, 2020) – to choose between random and fixed effects models as the limitations of pooled OLS are known (Arrelano & Bond, 1991).

In a fixed-effects model (FE), the intercept controls individual-specific and time-invariant characteristics (Torres-Reyna, 2007):

$$y_{it} = \alpha_i + \sum_{i=1}^{n} \beta_j x_{jit} + u_{it}, \quad (11)$$

where α_i – individual intercept in the i-th country.

The random effects (RE) model, on the other hand, makes it possible to estimate the effects of variables that are individually time-invariant:

$$y_{it} = \alpha + \sum_{i=1}^{n} \beta_j x_{jit} + u_{it}, \quad (12)$$

where:

$$u_{it} = \mu_i + \varepsilon_{it}, \quad (13)$$

where u_{it} – error component, μ_i – individual-specific random component, ε_{it} – idiosyncratic disturbance.

In our model, we have included (in addition to DESI) several control variables that have been reported in the literature as important determinants of economic growth. Based on Keynesian theory, we take in our models government expenditures and investments, which positively support GDP growth in the long run. In the empirical literature, we find many analyses which confirm the significant contribution of investments (e.g. Anderson, 1990) and government expenditures (e.g. Parui et al., 2021) in GDP growth. The study of Solow (1956) indicates that physical capital accumulation is an essential factor contributing to increasing production. It is why we include in our analysis the gross fixed capital formation as a potential determinant of economic growth. Since a positive relationship between ICT capital (i.e. its quantity and price) and GDP growth has been found in the literature (Niebel, 2018), we also use ICT capital compensation in our model. We take into account a total productivity factor (TFP) as a GDP growth factor. It measures the residual growth in total output of a firm, industry, or economy that cannot be explained by the accumulation of traditional inputs such as labor and capital. In the literature, we find some evidence that TPF contributes strongly to economic growth (e.g., Kim & Loayza, 2019; Saleem et al., 2019).

In our model, we also use indices that characterize the openness of the economy as control variables. We use in our model the openness index as a potential factor of economic growth according to the Melitz model (2003), which shows that trade openness leads to greater economic efficiency and economic growth on a macro scale. Based on Habib et al.

(2017) analysis, we take to our analysis the real effective exchange rate index, which movements can influence strongly on economic growth. Additionally, several macro-based papers on developed and developing countries suggest a positive effect of FDI inflows on economic growth, especially in a host country (Baiashvili & Gattini, 2020). It is why we use FDI as the potential factor of economic growth.

To the set of control variables, we have also added some social determinants of economic growth. We choose population growth and population size because they can affect GDP growth through many channels, e.g. via the age structure of a country's population or the size of the labour force (Peterson & Wesley, 2017). We also take the level of education, as it is essential for improving human capital and directly impacts economic growth. i.e. increasing the education level of workers improves their human capital, which increases the productivity of those workers and economic output (Barro, 2001). Additionally, the economic literature shows a significant positive long-run relationship between life expectancy and GDP per capita (or total GDP) in most countries (He & Li, 2020), so we decide to use life expectancy as a control variable in our model.

3. Data

The primary analytical tool applied in the sensitivity-based analysis was a MATLAB package – Composite Indicator Analysis and Optimization (CIAO) Tool (Lindén et al., 2021). This tool was used for the advanced assessment of Digital Economy and Society Index (DESI) values from 2015–2020 editions. Data on the index's value and its components are derived from the Digital Scoreboard (European Commission, 2020b). While, Table 1 shows the data used in the second part of the investigation together with their source.

The main goal of our study is to analyze the impact of DESI and its components on economic growth. To avoid the occurrence of the spurious relationship, we used panel models which, apart from the variables strictly resulting from DESI, also contain (in this case as control variables) factors commonly used in the analyzes of economic growth. The model, therefore, includes the following variables, which are considered to be GDP growth catalysts: total factor productivity (Saleem et al., 2019), government consumption (Pan, 2013), ICT capital compensation (Timme & Van Ark, 2005), gross fixed capital formation (Dritsakis et al., 2006), FDI (Li & Liu, 2005), population size and growth (Sibe et al., 2016) and life expectancy (Thalassinos et al., 2019). The study also considered openness (Fatima et al., 2020) and real effective exchange rate (Habib et al., 2017), which may have a negative impact on economic growth.

4. Research results and discussion

In the paper we try to verify two research hypotheses: (1) DESI's improvement, understood as weights coherence with variables importance can be achieved by reducing the set of variables and changing the weighting scheme and hypothesis; (2) Economic growth, measured by GDP per capita, can be well explained by both the original and optimized DESI. First, we want to describe DESI in detail and show how its dimensions are correlated with economic growth.

Table 1. Variables used in the investigation

Variable name	Description	Source
GDP _ pc	the logarithm of GDP per capita in euro	Eurostat
DESI _ o	the logarithm of the original DESI value	European Commission
DESI _ n	the logarithm of the new (optimized) DESI value	
RTFPA	the logarithm of the total productivity of the factors of production	Penn World Table (Feenstra et al., 2015)
Gov _ c	the logarithm of the share of government consumption at current PPPs	
ICT	the logarithm of the share of ICT capital compensation in GDP	
GFCF	the logarithm of the gross fixed capital formation as a percentage of GDP	
Openness	the logarithm of average imports and exports in relation to GDP	
REER	the logarithm of the real effective exchange rate index based on 2010	UNCTADstat
FDI	the inward foreign direct investment flow as a percentage of GDP	
Pop _ g	the population growth rate expressed as a percentage	Eurostat
LE	the logarithm of life expectancy	
Pop	the logarithm of population size	
Invest	the logarithm of investments ratio as a percentage of GDP	World Bank
Edu	the logarithm of average years of schooling	
Con _ o	the logarithm of the original DESI's *connectivity* pillar value	European Commission
HC _ o	the logarithm of the original DESI's *human capital* pillar value	
Internt _ o	the logarithm of the original DESI's *use of Internet services* pillar value	
DT _ o	the logarithm of the original DESI's *integration of digital technology* pillar value	
DS _ o	the logarithm of the original DESI's *digital public services* pillar value	
Con _ n	the logarithm of the new DESI's *connectivity* pillar value	
HC _ n	the logarithm of the new DESI's *human capital* pillar value	
Internt _ n	the logarithm of the new DESI's *use of Internet services* pillar value	
DT _ n	the logarithm of the new DESI's *integration of digital technology* pillar value	
DS _ n	the logarithm of the new DESI's *digital public services* pillar value	

4.1. Optimization of DESI weights

The correlation between the individual DESI pillars showed that there is at least a moderate, statistically significant correlation between almost every pair of pillars (Figure 8 – the darker the hue, the higher the correlation strength). The only exception is a relatively weak correlation between Pillar 1 (connectivity) and Pillar 4 (integration of digital technology). Figure 8 presents the situation in DESI 2020 edition; however, the trends were maintained

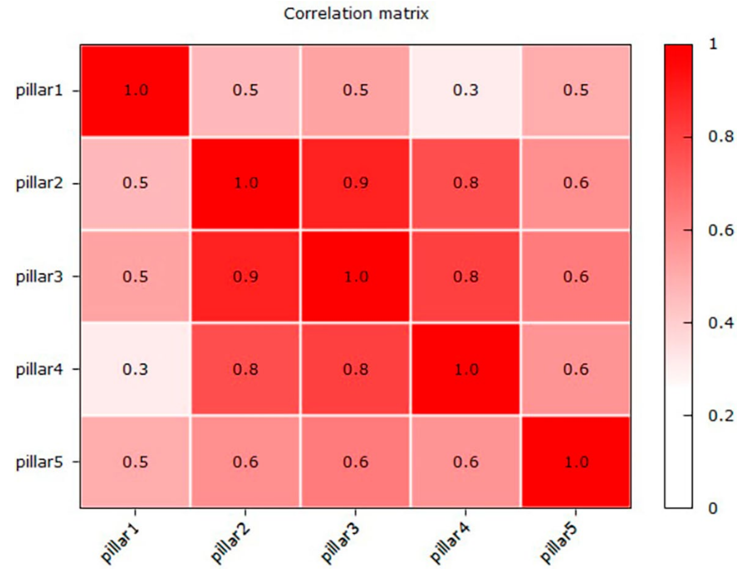


Figure 8. Correlation among pillars in DESI 2020 edition

throughout the entire period. A correlation between pillars may lead to a problem where the impact of a given dimension on the DESI is significant only due to that pillar's association. This, as a consequence, may cause no noticeable changes in the final score when a given pillar is removed from the aggregation formula. On the one hand, aggregation leads to a suppression of information, which is a form of reductionism. On the other hand, it may cause the double-counting of some underlying variables (OECD, 2008).

The determination of the effect of a given variable/pillar on the final ranking is possible based on the first-order sensitivity measure (Eq. (4)) and its decomposition into a correlated (Eq. (7)) and uncorrelated (Eq. (6)) part. Separate first-order sensitivity measures (S_i) were estimated for each analyzed period using penalized splines. The impact of each pillar on the DESI was first investigated. Then the pillars were treated as independent CIs, and individual subpillars were treated as an input variable. Then, each subpillar was treated as an output variable, shaped by individual variables. Therefore, a top-down approach was adopted, allowing the DESI to be broken down into prime factors. Figure 9 presents the estimated values of the first-order sensitivity measures for the individual pillars included in the DESI. The visualization applies to the DESI 2020 edition, while a detailed analysis was carried out for each ediion separately. It should be clarified that the value of S_i expresses the "importance" of a given variable/pillar. Still, there is no universal value differentiating significant variables/pillars from irrelevant ones as it depends on the measures under consideration and the applied methods of normalization, weighting, and aggregation. When analyzing this visualization, it can be noticed that regardless of the estimation method (linear – green bar or non-linear – yellow bar), the uncorrelated part (blue bar) of the S_i value is decisively lower, resulting from the correlation between variables and possibly indicating that the weight assigned to pillars may have an insignificant impact on the DESI overall score. The lack of negative values, which indicate a conceptual problem with the analyzed indicator, is a positive phenomenon (Becker et al., 2017).

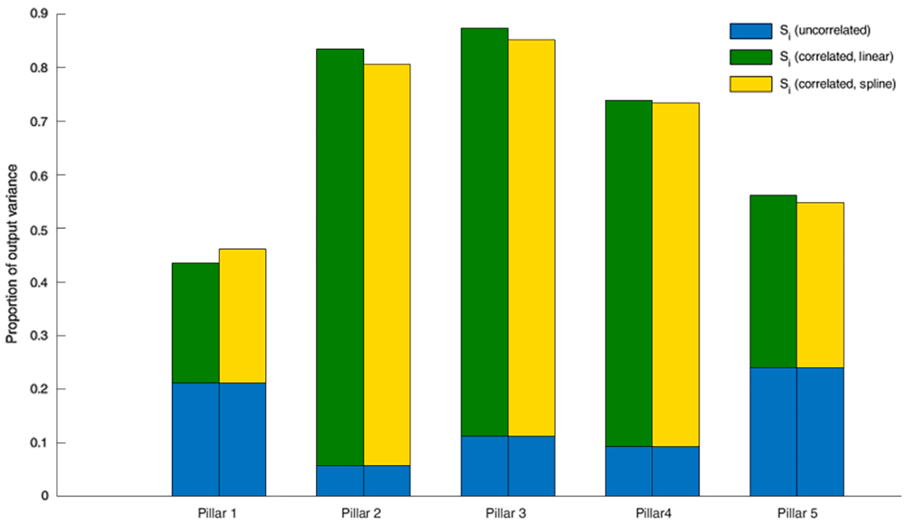


Figure 9. Penalized splines estimates of S_i (total bar) broken down into S_i^U (blue bar) and S_i^C (green or yellow bar)* in DESI 2020 edition. *Green – linear spline regression model, yellow – non-linear spline regression model

Table 2. Penalized splines estimates of S_i broken down into uncorrelated $\left(S_i^U\right)$ and correlated $\left(S_i^C\right)$ part

Dimension	Linear			Non-linear		
	S_i	S_i^U	S_i^C	S_i	S_i^U	S_i^C
Connectivity	0.43551	0.21116	0.22435	0.46188	0.21116	0.25072
Human capital	0.83437	0.05783	0.77654	0.80607	0.05783	0.74824
Use of internet services	0.87331	0.11275	0.76056	0.85196	0.11275	0.73921
Integration of digital data	0.73914	0.09326	0.64588	0.73437	0.09326	0.64111
Digital public services	0.56171	0.23991	0.32180	0.54782	0.23991	0.30792

A high proportion of the correlated part leads to the assumption that the DESI is volatile (Table 2) because the correlation between the dimensions dictates influence – not the weights assigned to them.

To balance the uneven impact of the indicators, weight optimization was performed (Eq. (9)). The results of this procedure are given in Table 3 and Figure 10, showing that, in many cases, the actual importance differs significantly from that assigned by the DESI's creators. In the entire analyzed period, Pillar 3 (use of Internet services) and Pillar 5 (digital public services) are "silent". This does not mean that these pillars and the variables that they include are irrelevant in the context of the country's digitization development. It sheds light on the fact that the applied method of aggregation causes their actual meaning to fade. The most impactful is Pillar 1 (connectivity), the weight of which fluctuates slightly over the analyzed period but is more than twice as high as that assigned by the creators of the index, and Pillar 4 (integration of digital services), which, however, loses its position in favour of Pillar 2 (human capital). While in DESI 2015 edition, the weight of Pillar 4 was 1.5 times

Table 3. Original and optimized weight for DESI dimensions

Dimension	Original	Optimized*					
		2015	2016	2017	2018	2019	2020
Connectivity	0.25	0.5234	0.5897	0.6175	0.6197	0.6150	0.5923
Human capital	0.25	0.0000	0.0001	0.0149	0.0534	0.1417	0.1865
Use of internet services	0.15	0.0000	0.0000	0.0000	0.0009	0.0000	0.0000
Integration of digital data	0.20	0.3573	0.3859	0.3248	0.3168	0.2432	0.1996
Digital public services	0.15	0.1193	0.0243	0.0428	0.0091	0.0000	0.0217

Note: *years refer to the DESI edition, each edition containing data from the previous year. European Commission (2020a).

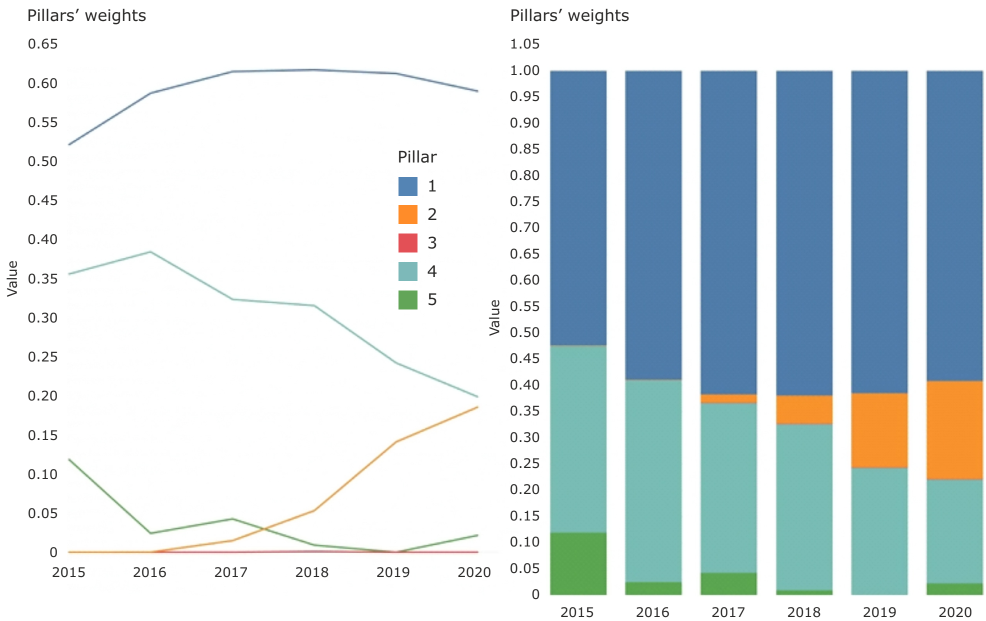


Figure 10. Optimized weight for DESI dimensions

higher than assigned to it by default, in DESI 2020 edition, it is already similar to the weight assigned by the index creators. In contrast, Pillar 2 (human capital) saw a change from "unimportant" to "significant".

Pillar 2 (human capital) turned out to be internally balanced to the highest extent, with both subpillars having almost the same weight. Pillar 1 (connectivity) also relatively well reflects the weights assigned by the DESI's creators. The only difference is that section B's optimal weight is 0.15 and for section D 0.25, while the opposite is true in the original. In Pillar 4 (integration of digital technology), part A's weight is three times higher than that of part B when the ratio is initially 60/40. The sensitivity-based analysis results suggest that removing the variables included in Pillar 3 (use of internet services) and Pillar 5 (digital public services) from the calculations does not significantly change the final ranking. This is confirmed by correlation coefficients (Table 4).

Table 4. Correlation among original and new DESI rankings

Year*	2015	2016	2017	2018	2019	2020
Spearman's rank correlation coefficient	0.9414	0.9026	0.9163	0.9179	0.9329	0.9217

Note: *years refer to the DESI edition, each edition containing data from the previous year. European Commission (2020a).

The appendix shows changes in the optimal weights of individual diagnostic variables making up each subpillar. The data repository includes a table with the most significant and completely "silent" variables.

4.2. DESI as a proxy of economic growth

The second part of the analysis included the verification of whether the DESI could be used as a proxy of economic development. Panel models were estimated for both the original and optimized DESI versions. This allowed us to check to what extent the reduction in diagnostic variables' set affects the analyzed index's discriminant possibilities. Different panel data models were estimated (n = 28 EU countries, T = 5), and all of them were strongly balanced.

Table 5 presents the estimated pooled and fixed effects models of GDP per capita for all EU countries. Breusch–Pagan and Hausman tests indicated that the fixed effects model is adequate for both the original DESI and its optimized version.

The panel regression estimations (Table 5) suggest that GDP per capita may as well be explained by both the original and optimized DESI. The estimated coefficients are positive and statistically significant, implying that digitalization is a crucial indicator of economic growth. Therefore, the obtained results confirm the Solomon and van Klyton (2020) research on the positive impact of digitization on the economy. However, the new form of the DESI loses some of its discriminatory power. Although no significant differences were noticed in the linear ordering of countries in the rankings, there is a considerable difference in the case of its strength as a regressor. This is most likely caused by the "invisibility" of Pillars 3 and 5 in the final composite indicator, and, in practice, the degree of the digitization of services may be essential for the development of the economy as a whole.

The estimation results revealed a positive and statistically significant impact of total productivity (RTFPA), population growth (Pop_g), real effective exchange rate (REER), and ICT capital compensation (ICT) on GDP per capita. In the model containing the new version of the DESI, citizens' life expectancy (LE) also has a statistically significant and positive effect on economic growth. On the other hand, GDP per capita in both models is negatively affected by the economy's openness, which is understood as average imports and exports in relation to GDP. Turunen et al. (2011) argue that openness is strongly connected with economies' competitiveness, with a crisis possibly leading to its weak or negative impact on economic growth.

An additional analysis was carried out, in which countries were divided into two groups depending on their GDP per capita. The dividing point was median GDP per capita in 2014. The estimation results showing the effect of the DESI (both variants) are presented in Table 6, while the fully estimated models are available in the data repository. As for the EU-wide model, the satisfactory properties of the model were obtained for the FE estimator. Due to the insufficient number of observations, it was not possible to estimate RE models.

Table 5. GDP per capita estimates 2015–2019 – all countries#

Variables	Old DESI		New DEIS	
	POOLS	FE	POOLS	FE
DESI _o	0.5292 ***	0.6104 ***		
DESI _n			0.4658 ***	0.3238 ***
RTFPA	1.0533 ***	0.8180 ***	1.6555 ***	0.9185 ***
Pop _g	0.0427 ***	0.0337 ***	0.0760 **	0.0396 ***
REER	0.8341 ***	0.8597 ***	0.7390 **	0.9268 ***
Openness	−0.1149 **	−0.2447 ***	−0.0595	−0.1895 **
LE	2.5743 ***	1.1692	2.1544 **	2.0021 **
Pop	−0.0722	−0.0522	−0.0216	−0.0150
Invest	0.0714	0.0443	0.4241	0.2897
Edu	0.0224	0.0215	0.1176 **	0.0386
Gov _c	−0.0691	−0.0754	−0.1002	−0.0828
ICT	0.0982 **	0.1028 ***	−0.3228 *	0.0654 ***
GFCF	0.0002	0.0003	−0.0001	0.0002
FDI	1.0533	0.8181	1.6555	0.9185
Obs.	140	140	140	140
R2	0.9526		0.9471	
Adj. R2	0.9481		0.9421	
Within-R2		0.9991		0.9990
LSDV-R2		0.9353		0.9298

Note : ***$p < 0.01$, ** $p < 0.05$, *$p < 0.1$. The variables' symbols used in the models are described in Table 1 in the previous section. Diagnostic tests are provided in the data repository. A year and country dummies are not reported in the table for the case of pooled OLS.

Table 6. GDP per capita estimates 2015–2019 – above and below median GDP per capita+

Variables	Countries with GDP per capita above the median				Countries with GDP per capita belowe the median			
	Old DESI		New DESI		Old DESI		New DESI	
	POOLS	FE	POLS	FE	POOLS	FE	POOLS	FE
DESI_o	0.7107***	0.2749***			0.6007***	0.8625***		
DESI_n			0.5108***	0.1405***			0.4422***	0.4825***

Notes: ***$p < 0.01$, ** $p < 0.05$, *$p < 0.1$. +a fully estimated model is available in the data repository – link available at the end of the article. A year and country dummies are not reported in the table for the case of pooled OLS.

Model estimates for the subpopulations support the conclusions from the main model. The impact of the DESI on economic growth was found to be positive and statistically significant; the DESI loses its discriminatory capacity in its new form. The results showing that the impact of broadly understood digitization is more significant in countries with lower GDP levels are not surprising either, which serves as a confirmation of the outcomes of the analyses carried out by Salahuddin and Gow (2016).

The repository also includes models in which the DESI pillars were used as explanatory variables. Pillar values were calculated using the original and optimized weights. The diagnostic tests once again indicated the correctness of FE models. In the model for all European Union countries, each index defining one of the DESI pillars is positive and statistically significant (the "use of Internet services" pillar is the exception in the original DESI version). In the models for the subpopulations, due to the initial value of GDP per capita, the previously observed trends were also maintained, i.e. the impact of individual components of digitization is much stronger in countries with smaller economies. The earlier conclusion that the "invisibility" in the ranking does not mean the actual lack of significance was confirmed because Pillar 5 (digital public services) has a statistically significant effect on GDP per capita in both variants.

Our findings are in line with the Deloite report (2021), in which the authors propose to make digital transformation a central part of development policy for EU economies. EU countries now have the opportunity to leverage the digital convergence measured by DESI to simultaneously support the EU's longer-term goal: economic convergence. These recommendations are particularly important for poorer EU countries and are in line with the OECD's (2020b) proposal for Latin American Countries to use strong digital transformation to overcome development traps LAC. To close the economic gap between poor and rich EU countries, some proactive actions will be needed on all levels, especially to boost the development and adoption of high-potential technologies. A great opportunity to implement this type of action is to use the Next Generation EU instrument (€750 billion funds to support the resilience and recovery of the Union), which also emphasizes digital infrastructure investments. These funds and programs target al. stages of digital development and will raise the digital standard of the Union's Member States, probably closing digital gaps as well as also economic gap within and between the Member States. Additionally, the digital transformation is one of two large-scale challenges for European countries, along with the green transformation. These two challenges are strongly linked: digital solutions have a critical role in helping Europe transition to a more sustainable economy and society. At the same time, the green transformation can boost the future of digital technologies, with reduced resource usage, waste, and greenhouse gas emissions.

Additionally, our research by establishing the link between DESI and economic growth supports the idea of focusing EU investments on digital convergence as part of the COVID-19 recovery plan. Baig et al. (2020) show that 75 percent of people using digital channels for the first time say they will continue to use them when things return to "normal". So, we recommend that European investments focus on the digital transformation process and its acceleration to overcome the COVID 19 crisis. In this context, it is essential to look for synergies between EU funds.

Conclusions

The variance-based analysis revealed that each indicator's influence on the index is unbalanced and strongly driven by correlations. As it was suspected, the problem of strong correlation led to double-counting and implicit weights. It is possible to obtain a very similar linear ordering of countries by halving the set of diagnostic variables (from 37 to 18) and removing the pillars concerning Internet services and digital public services entirely. It should be stressed once again that their insignificance means being blurred in the final ranking value. Therefore, their value is not visible in the DESI rank, but it does not mean that they are irrelevant in the context of countries' digital development.

Besides reducing the set of variables, it would also be necessary to drastically change the value of the weights assigned to each pillar, subpillar, and individual variables. The analysis pointed to significant discrepancies between the original weights and the optimized ones. The issues related to connectivity, the importance of which should be close to 0.60, have the most substantial effect on the final ranking. Due to the strong correlation, it is challenging to develop a well-balanced index without assigning zero weights to some elements. Moreover, composite indicators are inconsistent as linear aggregation is a poor way of summarising the information that, perhaps, should not be summarised in the first place. Combining certain pillars or modifying their content to provide conceptual coherence should perhaps be considered. Our research allows us to accept the hypothesis that DESI's improvement (understood as weights coherence with variables importance) can be achieved by reducing the set of variables and changing the weighting scheme.

After the optimization, a relatively small set of DESI subindicators can be used to analyze the country's digital transformation. Most of them come from commonly available sources. The current analysis of these variables allows each country to self-assess, so we recommend conducting a continuous analysis of digital transformation in regional or local dimensions. Our finding could also play a role in the discussion on the framework of regional indicators for digital transformation, which currently focus on firm-level approaches and changes in (regional) innovation systems.

We also positively verified the second hypothesis that economic growth, measured by GDP per capita, can be well explained by both the original and optimized DESI. Our results are of significant importance to policymakers regarding the measurement, support, and deepening of digital transformation. Existing metrics and assessment instruments fail to keep up with the rapid pace of digital transformation. To measure digital transformation, countries use existing indicators drawn from various areas, including education, innovation, trade, economic and social issues, or a composite indicator such as the DESI for EU countries. Our results reveal that for current and quick analyses of digital transformation development or some international comparisons in this area, it is appropriate to consider only several indicators such as the coverage of broadband (fixed, fast, 4G), level of software skills, and the percentage of enterprises analyzing big data and selling products and services online. These indicators are most crucial from the digital transformation level point of view.

As digital technologies continue to reshape society and the economy dramatically, many countries are pursuing large-scale supporting initiatives in this area. Our study indicates that

EU countries should develop fast broadband plus 4G technologies as well as invest in all education programmes aimed to create a new generation capable of adapting and working with ICTs. Citizens and employees with high digital skills are of common interest to both the state and employers, so building partnerships between the state and private sector to make people more familiar with ICTs is strongly recommended.

Additionally, our study confirms that the DESI is useful for explaining changes in GDP per capita. This is good news for the poorest EU countries because the gap between rich and poor countries in the European Union can be closed or eliminated by fast and intensive digital transformation. It is crucial for each country that uses its natural resources (such as oil or minerals) or export trade to ensure GDP growth and is still unable to take off to reach a high development stage.

Our study have some limitations. A fundamental limitation when it comes to the use of SA is the need to calculate the correlated and uncorrelated share for each of the analyzed years separately, as these depend on the degree of variability and correlation of variables. As a result, the weights change over time, which can be considered a disadvantage of this approach. Moreover, there is no clear guidance in the literature regarding when a given variable can be considered "mute" and what volume of difference between the original and optimal weight does not justify the need for changes. So far, these questions remain unanswered but are of interest to the authors of this article. We plan to conduct a series of simulations and experiments, and then prepare appropriate guidelines for users of synthetic meters.

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Author contributions

M.O. and M.K-CZ. contributed equally to this work in the following aspects: conceptualization; validation; formal analysis; methodology; investigation; resources; writing–original draft preparation; visualization; supervision; project administration.

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The authors declare no competing financial, professional, or personal interests from other parties.

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APPENDIX

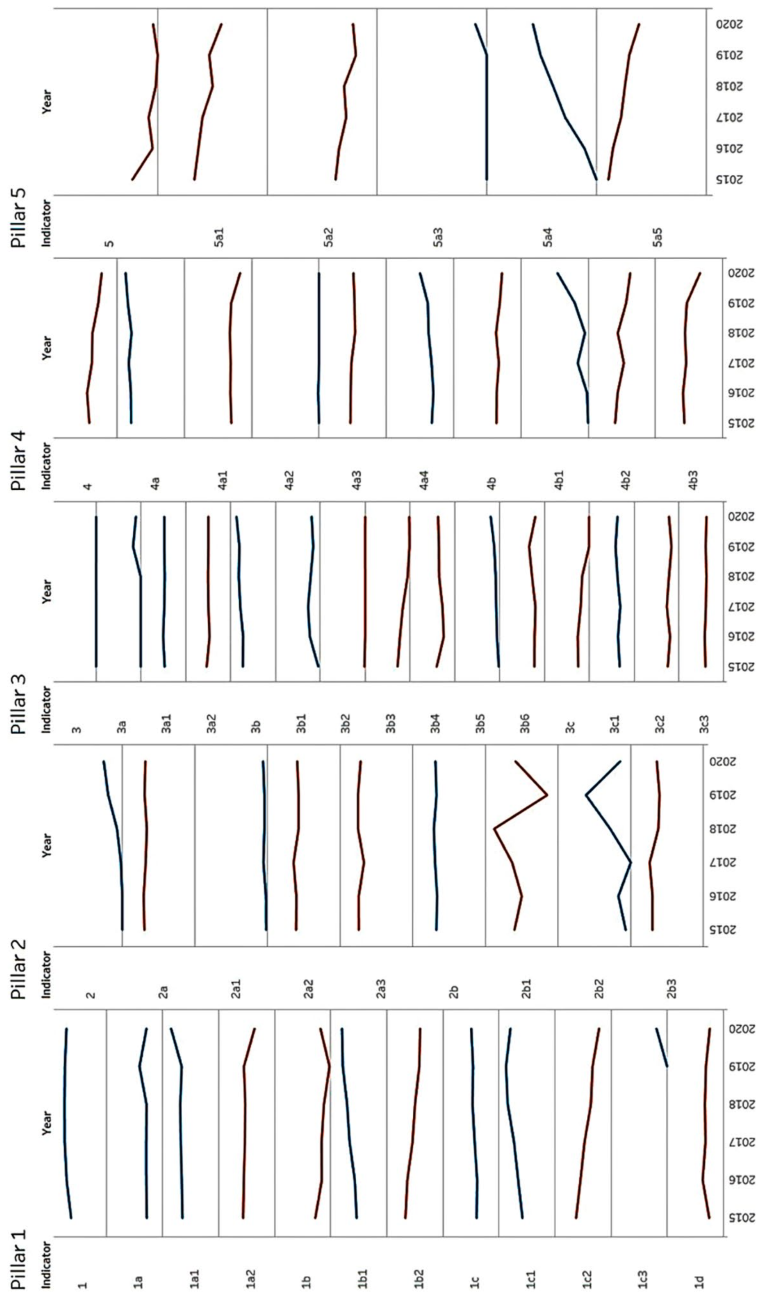

Figure A1. Optimized weight for individual variables within DESI's dimensio