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Article

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Amfiteatru Economic Journal

Provided in Cooperation with:

The Bucharest University of Economic Studies

Suggested Citation: Rîndaşu1, Sînziana-Maria; Ionescu-Feleagă, Liliana; Ionescu, Bogdan-Ştefan; Topor, Ioan Dan (2023) : Digitalisation and Skills Adequacy as Determinants of Innovation for Sustainable Development in EU Countries: A PLS-SEM Approach, Amfiteatru Economic Journal, ISSN 2247-9104, The Bucharest University of Economic Studies, Bucharest, Vol. 25, Iss. Special Issue No. 17, pp. 968-986, <https://doi.org/10.24818/EA/2023/S17/968>

This Version is available at:

<https://hdl.handle.net/10419/281744>

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DIGITALISATION AND SKILLS ADEQUACY AS DETERMINANTS OF INNOVATION FOR SUSTAINABLE DEVELOPMENT IN EU COUNTRIES: A PLS-SEM APPROACH

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| <p>Please cite this article as: Rîndaşu, S.M., Ionescu-Feleagă, L., Ionescu, B.S. and Topor, I.D., 2023. Digitalisation and Skills Adequacy as Determinants of Innovation for Sustainable Development in EU Countries: A PLS-SEM Approach. <i>Amfiteatru Economic</i>, 25(Special Issue 17), pp. 968-986.</p> <p>DOI: https://doi.org/10.24818/EA/2023/S17/968</p> | <p>Article History Received: 22 August 2023 Revised: 14 September 2023 Accepted: 26 September 2023</p> |
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Abstract

Increasing innovation among the European Union (EU) countries became a primary concern, as it can contribute to higher competitiveness, generate new business opportunities, and promote the achievement of the sustainable development goals. This paper aims to examine the extent to which the EU countries' level of digitalisation and skills adequacy impact the innovation output, as well as to determine whether the level of digitalisation can lead to an increase in the individuals' competencies and employability. For this research, we leverage a Partial Least Squares - Structural Equation Modelling technique. The data used to achieve the study's objective was collected from composite indicators computed for the 27 EU countries for a period of analysis spanning the years from 2017 to 2020. As a proxy for the digital performance, we use the Digital Economy and Society Index, while for skills adequacy and innovation output, we utilise the European Skills Index and the dimension of innovation output dimension of the Global Innovation Index. The results indicate a statistically significant impact between the level of digital performance and innovation output, with a moderate effect size, partially mediated by skill adequacy. Moreover, the findings emphasise that a higher level of digitalisation determines an increase in the individuals' employability and competencies. The study enhances the understanding of the complex relationship between digitalisation, skills, and innovation by shedding new light on the trajectories' coevolution of the analysed constructs, presenting some implications for policymakers and governments, and providing theoretical suggestions for future research.

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Keywords: digital performance (DP), digitalisation, innovation (IO), skills adequacy (SKA), sustainable development, EU countries

JEL Classification: O3, O11, O15

Introduction

The permeative character restructures economic and social activities. In this context, at the microeconomic and macroeconomic levels, there is an urge to leverage as many new information technology (IT) solutions as possible to gain additional competitive advantages and improve the level of innovation. In the case of the European Union (EU), sustainable economic growth and improving the countries' innovation level are among the series of Sustainable Development Goals - SDG (Eurostat, 2023); thus, developing these areas will support the EU in delivering on the 2030 Agenda.

The link between digitalisation and innovation has been and continues to be a highly researched topic, with most studies focusing on the relationship at the firms' level. Although until recently the digitalisation's role in creating and accelerating innovation was considered implicit among scholars, new studies suggest that the underlying mechanisms are particularly complex (Kastelli et al., 2022; Ning et al., 2023), arguing the need to question the status quo, as digital technologies, depending on their type, might act as inhibitors of innovation (Usai et al., 2021).

This controversy led researchers to consider other factors that might mediate the relationship. Therefore, Kastelli et al. (2022) investigate the Greek manufacturing sector and discover that the absorptive capacity enhances the benefits of digitalisation, improving the contribution of the digital capacity to innovation performance. Similarly, Otioma (2022) and Gong et al. (2023) notice the same positive direct link, enhanced by organisational learning, defined as knowledge acquisition (accumulation), dissemination, and integration. Other studies focus on the importance of entrepreneurial orientation (Kraus et al., 2023), regional digital industry (Li et al., 2023a), and internal research and development (R&D) activities (Usai et al., 2021; Radicic and Petković, 2023). Unquestionably, digitalisation also impacts the required set of competencies, leading to the individuals upskilling (Pedota et al., 2023). As no form of innovation can be human-less, a complete set of skills is required to support the creation process. In this regard, Ciarli et al. (2021) recommend researchers to investigate more the digitalisation, innovation, and skills to enhance the understanding of the factors' coevolution.

Scholars have already provided great insight into this triad; however, most studies are related to the business environment, while less attention is being paid to the countries' level. The existing studies that address this matter at the countries' level are focused mainly on the direct coevolution of digitalisation and innovation as antecedents of competitiveness (Marti and Puertas, 2023) and the link between the different variables that form innovation (Huang and Yu, 2022; Bate et al., 2023; Oturakci, 2023). To address this research gap, the present study aims to perform an exploratory analysis to examine the extent to which the countries' level of digitalisation and the skills adequacy determine an increase in the states' innovation output. Moreover, we are also investigating whether the degree of digitalisation can improve individuals' competencies and employability and if the skills' adequacy can mediate the relationship between digitalisation and innovation. To achieve this scope, we employed a Partial Least Squares - Structural Equation Modelling technique, focusing on the EU

countries between 2017 and 2020. As proxies for the digitalisation, skills adequacy, and innovation, we used dimensions and sub-dimensions of the composite indicators Digital Economy and Society Index - DESI (European Commission, 2022), European Skills Index – ESI (Cedefop, 2022), and Global Innovation Index – GII (World Intellectual Property Organisation, 2022). Therefore, this study enhances the understanding of the triad coevolution and provides new insights into the skills adequacy's importance in mediating the relationship between the states' levels of digitalisation and innovation output.

The remainder of the paper comprises four parts. The first part reviews the relevant literature on the topic, focusing on the relationships between the analysed constructs and introducing the research hypotheses. The following part describes the methodology employed, focusing on the secondary data reliability, collection, and analysis. The third section presents the results and discusses the findings, while the last section presents conclusions, limitations, and future research directions.

1. Literature review and hypotheses development

1.1. Digitalisation and innovation

The prior literature examined the relationship between digitalisation and innovation by focusing on the dynamic capability theory (Tortora et al., 2021; Tajudeen et al., 2022), advocating that companies, by firstly managing resources efficiently (digital technologies), can explore and exploit the innovation capabilities. By analysing more than 5 000 environmental patents, Leyva-de la Hiz et al. (2019) highlight that companies from states with environmental weaknesses are wielding digital solutions to generate sustainable innovations. However, the direct relationship between digitalisation and innovation is an important topic of research (Kastelli et al., 2022), as some studies consider this link as being implicit, and other researchers question its status quo, arguing that not all digital technologies are fostering innovation outputs (Usai et al., 2021).

By analysing the GII's pillars, Ekici et al. (2019) argue that the countries' technological readiness level improves innovation capacities. Other researchers have analysed the structure of GII to determine which of the innovation inputs impact the outputs. Oturakci (2023) discovers a negative correlation between the infrastructure pillar - which includes the assessment of the countries' information and communication technology (ICT), along with the evaluation of the general infrastructure and ecological sustainability, and the knowledge and technology output, while highlighting a positive correlation between the nations' infrastructure and the creative output. Similarly, after examining the relationship between digitalisation and environmental innovation in 24 EU countries, Hung et al. (2023) highlights the importance of the digital business. From the coevolution context suggested by Ciarli (2021), Marti and Puertas (2023) analyse the countries' innovation capacity and digitalisation level as antecedents of competitiveness by using DESI and GII as secondary data for the examination, observing a stable development in terms of digitalisation and innovation, but with a significant gap between north-central and south-eastern Europe. Based on these facts, we assume the following:

H₁. The level of digitalisation impacts the innovation output in EU Countries.

1.2. Digitalisation and skills adequacy

A large and growing body of literature investigates the relationship between digitalisation and skills, focusing on the impact of digitalisation as a determinant of skills improvement. From a historical point of view, in the case of highly digitalised industries, the skills upgrading's rate is significant (Autor et al., 1998). In terms of the digitalisation's impact on the skills adequacy, researchers propose new approaches to leverage the ICT's benefits for professional upskilling and reskilling (Tay et al., 2022). Vial (2019) argues that the digital transformation has an increased potential of determining employees to step outside the limits of their functions, thus leading to an increase in the individuals' set of skills. Analysing the relationship between digitalisation and professional development by adopting an identity-centred approach, Wallin et al. (2022) found that this link is significantly influenced by the individuals' work meaning and their perception of themselves, concluding that the work-identity misalignments can be addressed by improving the career crafting level. Although in exceptional cases the personal engagement leads to an increase in the level of skill (Dima et al., 2022), in the context of accelerated digitalisation, this relationship is not easily quantifiable.

The effect of digitalisation on employment represents an extensively researched topic that manages to capture different perspectives. Some studies suggest that the increase in digitalisation leads to both job creation and destruction (Hunt et al., 2022), while other scholars focus on the digitalisation's creative or destructive character. By analysing the changes in the worker flows in the context of increased investments in automation-intensive goods for more than 30 000 manufacturing companies between 2002-2015, Domini et al. (2021) highlight that digital and automation technologies can boost the number of employees due to the creation of new job opportunities. The findings are also supported by the study conducted by Klenert et al. (2023), extending the scope outside the manufacturing sector with a neutral effect on low-skill workers. In the same vein, after examining the EU citizens' perception regarding digitalisation, Vasilescu et al. (2020) found a positive attitude toward digitalisation in the EU countries, but it also discovered vulnerable groups in terms of exposure to the digital divide, stressing the need for improving both the individuals' skills adequacy and their confidence in the set of competencies.

As the impact of digitalisation on upskilling is an important aspect, scholars are focusing on the companies' abilities to help employees develop the necessarily set of skills. While large organisations can leverage a series of resources to facilitate the process, in the case of small and medium enterprises, there is a particular level of concern (European Commission, 2020). However, a recent study, focusing on more than 17,000 Italian companies (Pedota et al., 2023), emphasised that, regardless of the size, companies understand the importance of the employees' ICT competencies, developing strategies to upskill the workforce. By shifting the perspective to the macroeconomic level, policymakers are expected to be responsible for improving the individuals' skills adequacy. Therefore, we hypothesise that:

H₂. The level of digitalisation impacts the skills adequacy in EU countries.

1.3. Skills adequacy and innovation

The positive relationship between skills adequacy and creating innovation outputs is obvious, as even nowadays, given the technological advancement, there is no such thing as a human-

less innovation (Juhász et al., 2022). Similar to the relationship between digitalisation and innovation, this link can also be analysed through the academic lenses of dynamic capability theory. The matter in this context is to examine the types of competency that improve the impact on innovation.

Various studies have examined the taxonomies and their effect on creating innovation. Brunow et al. (2018) discover that although both creative and STEM (Science, Technology, Engineering, and Maths) workers improve the firms' innovation level, in the case of the creative workers, this link is limited to the companies' boundaries, while in the case of the STEM employees, there are fewer restrictions. However, given the shifting demands of the business environment regarding sustainability-related aspects, along with the need for social innovations, the importance of transversal competences is revealed (Caeiro-Rodríguez et al., 2021; Svennevik and Saidi, 2022). In this regard, Shamzzuzoha et al. (2022) stress the need to understand the required skills to facilitate the implementation of sustainable innovations. Based on these facts, we hypothesise as follows:

H₃. Skills adequacy positively impacts the generation of innovation outputs in EU countries.

Given the two sub-pillars of the GII's innovation output (World Intellectual Property Organisation, 2022), it can be observed that both of the items are related to digitalisation. However, in the case of the creative outputs, a higher share is related to aspects not directly linked to digitalisation. Starting from the coevolution between digitalisation, skills adequacy, and innovation suggested by Ciarli et al. (2021), researchers started analysing this triad either based on the innovation indexes (Marti and Puertas, 2023; Oturakci, 2023) or through empirical analysis at the companies' level (Pedota et al., 2023). From a technical perspective, Li et al. (2023b) demonstrate that digital development, through an adequate set of skills, can lead to the development of innovations, arguing that by optimising the ICT solutions, companies could improve their sustainable performance. Thus, we hypothesise that:

H₄. Skills adequacy mediates the relationship between the EU countries' level of digitalisation and innovation output.

2. Methodology

The scope of the research is to determine the influence of the states' level of digital performance and skills adequacy on the innovation output across the EU countries. One subsequent research sub-objective is to empirically test the impact of the countries' digitalisation on the skills adequacy and to examine whether this impact determines changes in the influence of digital performance on innovation outputs. Based on these assumptions, we propose the following model (Figure no. 1) derived from the previously defined research hypotheses.

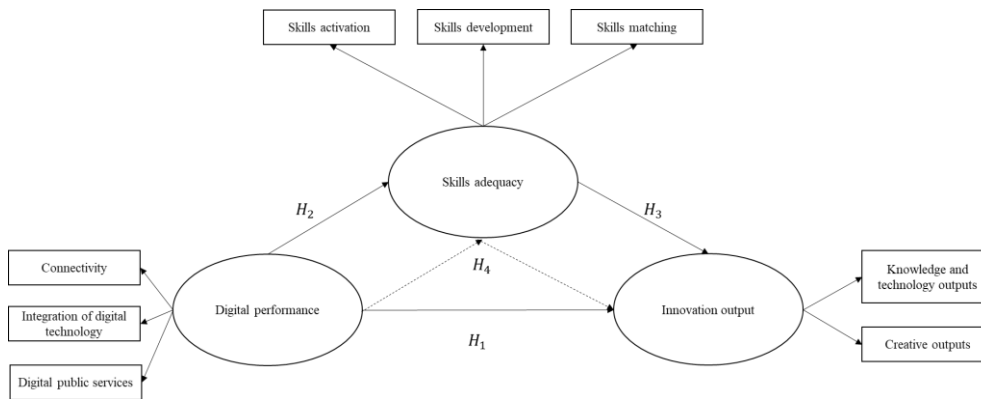


Figure no. 1. The proposed model

This study adopts a quantitative approach to investigate the factors that can determine the improvement of innovation output. Firstly, we present the data used in this exploratory analysis, followed by the statistical techniques wielded to test the proposed hypotheses.

2.1. Data collection

The data used for this research was collected from composite indicators computed for all 27 EU countries, between 2017-2020, with a total sample of 108 valid cases. As a proxy for the countries’ level of Digital Performance, we used the Digital Economy and Society Index (DESI), while for the skills adequacy and innovation outputs, we utilised as proxies the European Skills Index (ESI) and the Global Innovation Index (GII). Each composite indicator wielded has a series of dimensions (measured on a scale from 0 to 100) with the sub-dimensions presented in Table no. 1.

Table no. 1. Items and constructs used for the study

| Construct (abbreviation) | Dimension (abbreviation) | Sub-dimensions | Source |
|--------------------------|---|--|---|
| Digital performance (DP) | Connectivity (CON) | broadband price index fixed broadband coverage fixed broadband take-up mobile broadband | European Commission - DESI (2022) Reports’ years: 2018-2021 |
| | Integration of digital technology (IDT) | digital intensity digital technologies for businesses e-commerce | |
| | Digital public services (DPS) | e-government | |
| Skills adequacy (SKA) | Skills activation (SA) | labour market participation transition to work | Cedefop – ESI (2022) Reports’ years: 2018-2022 |
| | Skills development (SD) | basic education training and other education | |
| | Skills matching (SM) | skills mismatch skills utilisation | |

| Construct (abbreviation) | Dimension (abbreviation) | Sub-dimensions | Source |
|---------------------------------|--|---|---|
| Innovation output (IO) | Creative outputs (CO) | creative goods and services intangible assets online creativity | World Intellectual Property Organisation (2022) - GII Reports' years: 2018-2021 |
| | Knowledge and technology outputs (KTO) | knowledge creation knowledge diffusion knowledge impact | |

For the current research, we employed the dimensions as items of the constructs. From DESI we used all the dimensions except for the Human Capital, which has as sub-dimensions the “internet user skills” and “advanced skills and development”. The “internet user skills” overlaps with one item of the ESI sub-dimension (“training and other education”). In contrast, the “advanced skills and development” refers to the number of ICT specialists and companies that provide ICT training to their employees. Although there is no overlap between the base indicators of the second sub-dimension with any of SKA’s dimensions, the number of ICT professionals determines changes in the SKA’s base indicators, which led to the decision to disregard the HC dimension when performing this analysis. From GII we only used the dimensions referring to the EU countries’ innovation output, defined by the World Intellectual Property Organisation (2022) as “the result of innovative activities within the economy”, given the study’s scope. In contrast, the innovation input refers to the factors that enable and facilitate innovation activities.

The relationship between digitalisation and workforce’s skills can be complex and multifaceted, the aim of this study not being to generally define the direction of the relationship between digitalisation and skills adequacy, but only through the lens of the items used to create the two composite indices. Thus, we advanced the hypothesis H₂ that digital progress at the country’s level, driven by the need to increase competitiveness and fostered by government initiatives, is leading to changes in the individuals’ skill set, with human resources having to develop new skills to meet the ongoing business needs generated by Industry 4.0.

As the labels used by Cedefop for the skills matching sub-dimensions might create confusion, especially in the case of the SM’s sub-dimension “skills mismatch”, we provide the framework’s definition as presented in the latest report (Cedefop, 2022, p.7): “the pillars can be interpreted as a process: the development of an individual’s skills influences their activation in the labour market and consequently their matching to employment”. Thus, the sub-dimensions values have not been reversed for the current analysis.

Both ESI and GII are audited indicators, constructed based on the methodological guidelines provided by the Joint Research Centre. DESI is not audited, but it “was developed according to the guidelines and recommendations in the OECD/JRC’s Handbook on constructing composite indicators: methodology and user guide” (European Commission, 2022, p.77). The descriptive statistics of the items used are presented in Table no. 2.

Table no. 2. Descriptive statistics of the items used

| Item | N | Min. | Max. | Mean | Standard deviation | Skewness | Kurtosis |
|------|-----|-------|-------|-------|--------------------|----------|----------|
| CO | 108 | 20.30 | 57.90 | 40.97 | 8.76 | -0.05 | -0.70 |
| CON | 108 | 13.40 | 72.12 | 35.61 | 9.74 | 0.60 | 1.28 |
| DPS | 108 | 9.80 | 86.26 | 57.10 | 15.81 | -0.66 | 0.40 |
| IDT | 108 | 11.41 | 53.41 | 29.27 | 9.57 | 0.24 | -0.25 |
| KTO | 108 | 23.70 | 63.70 | 39.48 | 10.13 | 0.57 | -0.51 |
| SA | 108 | 1.70 | 87.70 | 53.87 | 18.99 | -0.84 | 0.29 |
| SD | 108 | 26.00 | 89.60 | 51.49 | 13.96 | 0.23 | -0.30 |
| SM | 108 | 10.00 | 93.30 | 54.59 | 19.33 | -0.62 | 0.07 |

2.2. Data analysis

The data and the proposed model were analysed using the SmartPls 4 software (Ringle et al., 2022). The Partial Least Squares - Structural Equation Modelling (PLS-SEM) technique is considered appropriate for the research's scope as it allows the simultaneous estimation of multiple causal relationships between one or more independent variables and one or more dependent variables (Hair et al., 2019), suitable for the analysis of composite indicators in different countries (Fernández-Portillo et al., 2020; Buitrago et al., 2021). Furthermore, PLS-SEM is mainly used to develop exploratory research (Hair et al., 2017). Firstly, we assessed the measurement model that establishes the reliability and validity of the construct and then proceeded to evaluate the structural model that determines the significance of the hypothesised relationships by running a bootstrap analysis with 5000 samples.

In order to test the hypotheses formulated, we conducted the analysis in three stages. The first stage focuses on examining the measurement model through a confirmatory factor analysis to assess the reliability and validity of each construct. The second stage was represented by the bootstrapping procedure employed to test the proposed hypotheses. In the third step, we conducted an importance-performance map analysis (IPMA) to extend the PLS-SEM's results considering each construct's performance.

In the first stage, we examined the items' loadings, Cronbach's Alpha, average variance extracted (AVE), the composite reliability (CR), and the discriminant validity for the initial assessment. In table no. 3, we present the items' loadings, the internal consistency, and the convergent validity. All the loadings, except for CON and SM, exceed the threshold of 0.708 (Hair et al., 2019). The other two items' loadings, although not above the recommended value, exceed the 0.4 value and do not impact the convergent validity of the dimensions (Hair et al., 2017); thus, the items were not eliminated from the measurement model. Although, in the case of SKA, the Cronbach's Alpha is slightly below the 0.7 threshold (Taber, 2018), "values of 0.60 to 0.70 are acceptable in exploratory research" (Hair et al., 2022, p. 119), Cronbach and Shavelson (2004, p. 402), stating that "a small mathematical detail (that) causes the alpha coefficient to run a trifle lower than the desired value. Furthermore, analysing the relationship between Cronbach's Alpha and CR, Peterson and Kim (2013) suggest that the two analyses can be used interchangeably. Therefore, as can be noticed, the model's internal consistency and convergent validity requirements are met.

Table no. 3. Assessment of the reflective measurement model

| Dimension | Cronbach's Alpha | rho_A | CR | AVE | Item | Item loadings |
|-----------|------------------|-------|-------|-------|------|---------------|
| DP | 0.812 | 0.905 | 0.884 | 0.721 | CON | 0.701 |
| | | | | | DPS | 0.929 |
| | | | | | IDT | 0.899 |
| SKA | 0.676 | 0.791 | 0.795 | 0.585 | SA | 0.872 |
| | | | | | SD | 0.903 |
| | | | | | SM | 0.423 |
| IO | 0.709 | 0.739 | 0.871 | 0.772 | CO | 0.910 |
| | | | | | KTO | 0.847 |

To assess the discriminant validity, we used both the Fornell-Larcker criterion and the heterotrait-monotrait (HTMT) ratio, as the items' loadings variation is relatively strong; therefore, the risk for the Fornell-Larcker criterion's performance to be altered decreases (Voorhees et al., 2016). As shown in table no. 4, all the dimensions have the square root of the average variance extracted greater than the correlation between the dimensions and any other dimension. Similarly, the HTMT ratios are below the conservative threshold of 0.85 (Franke and Sarstedt, 2019).

Table no. 4. Discriminant validity assessment

| Dimension | Fornell-Larcker criterion | | | HTMT ratios | | |
|-----------|---------------------------|--------------|--------------|-------------|-------|-----|
| | DP | IO | SKA | DP | IO | SKA |
| DP | 0.849 | | | | | |
| IO | 0.588 | 0.879 | | 0.725 | | |
| SKA | 0.523 | 0.594 | 0.765 | 0.557 | 0.717 | |

The robustness check of the dataset was performed using Gaussian Copula analysis, available in SmartPls 4, which allows the detection and correction of data endogeneity issues. The results obtained exceed the 0.05 threshold specified in the literature, thus also excluding causes that can lead to endogeneity, such as "measurement errors, simultaneous causality, common method variance, and (un)observed heterogeneity" (Hult et al., 2018, p.3).

3. Results and discussions

The results of the bootstrapping procedure (Table no. 5) depicts that the first three formulated hypotheses are accepted.

H₁ presumed that a country's DP impacts the IO proxied through CO and KTO. The result indicates the existence of a significant relationship ($\beta=0.381$; T-value=5.874; $p<0.001$); therefore, H₁ is accepted. This finding confirms the Kalinić and Sternad (2015) and Marti and Puertas (2023) studies' results after examining the link between digitalisation and innovation in the EU countries. In the organisational context, prior studies highlighted that the industries' adoption of digital technologies leads to transformations characterised by a higher level of innovation (Alshawaaf and Lee, 2021; Tajudeen et al., 2022). Given this outcome, policymakers should focus more on facilitating the companies' navigation in Industry 4.0 by providing a series of incentives to determine organisations to become early

adopters of the emerging technologies, improving the digitalisation level of public services and supporting individuals in gaining a sufficient level of skills to assist companies in the process of digital transformation. Furthermore, a higher level of innovation seems to lead to an increase in competitiveness (Clark and Guy, 1998; Marti and Puertas, 2023), thus generating economic growth (Boikova et al., 2021).

The second hypothesis (H_2) assumes that a country's level of DP has a significant impact on SKA ($\beta=0.523$; T-value=7.761; $p<0.001$). The result highlights that a higher level of the country's DP leads to the improvement of SKA. This outcome is in line with previous literature focusing on the individuals' skills development and the digital economy, as a higher level of digitalisation can lead to the skills' improvement in an organisational environment (Ekici et al., 2019; Pedota et al., 2023), especially when the labour market is subject to automation and individuals have to demonstrate an appropriate set of skills (Nania et al., 2019). Given the complexity of the skills adequacy, proxied by ESI, through the three main dimensions constructed on six sub-dimensions, as presented in table no. 1, determined by wielding 15 base statistical indicators from various international datasets, a high level of digital performance does not impact only the digital skills, but also other factors such as a higher employability rate amount of recent graduates and an increased labour-market participation. In terms of the skills matching dimension, lower values of the five base indicators (reverse-coded in the index's reports) highlight a better outcome; thus, the increase of digital performance among countries leads to a decrease of the dimensions' values, a higher level of digital performance reducing the long-term unemployment rate (Başol and Yalçın, 2021). However, other researchers adopt a more pessimistic view suggesting that a higher level of DP, especially in an environment dominated by artificial intelligence, determines a reduction in the number of jobs (Acemoglu and Restrepo, 2020). Therefore, the extent to which this outcome will continue to last is a subject of further analysis.

As individuals might not always regard self-directed learning as a positive outcome, but rather as a stressful burden (Lemmetty and Collin, 2020) and keeping in mind that the digital capabilities of industries and countries continue to expand, lawmakers should carefully investigate the labour market required set of skills and ensure a proper level of education for the individuals and promote a shared partnership between the stakeholders; otherwise, there is a significant risk that countries will be unable to leverage the digitalisation's full potential (Spencer and Slater, 2020). At the EU level, through the Recovery and Resilience Strategy, countries are expected to improve their DP; however, in terms of the skills pillar, most countries have a high level of unachieved objectives (European Commission, 2023).

The third hypothesis (H_3) states that SKA positively impacts IO ($\beta=0.394$; T-value=6.347; $p<0.001$). As innovation represents one of the main pillars of sustainable economic growth (Zygiaris, 2022), being the driving force that leads to business value creation (Vitezić and Vitezić, 2015), Kahn (2018) argues that innovation can be perceived not only as an outcome or process, but also as a mindset supported by the individuals' level of skills. Therefore, this result confirms the link between skill adequacy and innovation. Moreover, previous studies have highlighted that investing in Corporate Social Responsibility policies might improve the individuals' skills and the improvement of the states' IO (Seitz, 2016).

Table no. 5. The path coefficients (direct effect) of the structural equation model

| Path | β | Sample Mean | Standard Deviation | T-Value | P Values | Hypotheses |
|----------------------|---------|-------------|--------------------|----------|----------|---------------|
| DP \rightarrow IO | 0.381 | 0.379 | 0.065 | 5.874*** | 0.000*** | H1: Supported |
| DP \rightarrow SKA | 0.523 | 0.532 | 0.067 | 7.761*** | 0.000*** | H2: Supported |
| SKA \rightarrow IO | 0.394 | 0.398 | 0.062 | 6.347*** | 0.000*** | H3: Supported |

Note: *p<0.05; **p<0.01; ***p<0.001.

As can be noticed in figure no. 2, DP explains 27.4% of the variance of SKA ($R^2=0.289$), suggesting a substantial predicting power of the structural model according to Cohen (1988, 1992) and a weak effect according to Chin (1998).

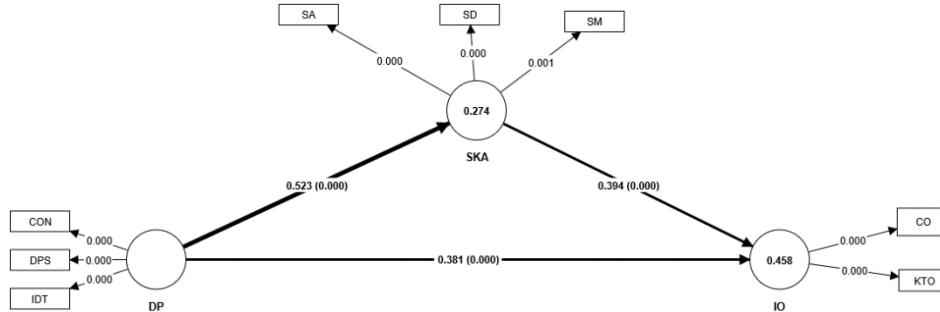


Figure no. 2. Structural model

By analysing the effect size between these two constructs, it can be concluded that the effect is significant ($f^2=0.377$; T-value=2.582; $p<0.001$), as it exceeds the 0.35 threshold proposed by Hair et al. (2017). The impact of DP and SKA on IO ($R^2=0.458$) highlights that the two dimensions could explain 45.8% of the variation. In terms of the effect size, the DP's and SKA's impacts on IO are moderate and statistically significant (DP \rightarrow IO: $f^2=0.195$; T-value=2.466; $p=0.014<0.05$; SKA \rightarrow IO: $f^2=0.208$; T-value=2.584; $p=0.010<0.05$).

Ciarli et al. (2021) argue that there is a complex relationship between innovation, digitalisation, and skills, considering that it is necessary to understand the trajectories' coevolution to enhance the knowledge regarding the industries' organisation and dynamics. Therefore, in addition to the direct effect, this study also tested the mediation effect of SKA on the link between DP and IO. As the proposed model respected the assumptions formulated by Baron and Kenny (1986), an additional analysis was employed to evaluate the mediating role of SKA. We can observe a partial mediation through SKA in terms of the specific indirect effect of DP on IO. Although DP has a statistically significant direct effect on IO, as presented in Table no. 5, by analysing the indirect effect ($\beta=0.206$; T-value=4.909; $p<0.001$) and the total effect of DP in IO ($\beta=0.588$; T-value=10.760; $p<0.001$) it can be noticed that this is significant. The analysis results highlight that the relationship between DP and IO is partially mediated by SKA, thus determining the acceptance of H₄.

This result highlights that the increase in IO determined by the countries' DP can be enhanced if SKA is improved. This finding has a series of important implications as one of the six pillars of recovery and resilience, namely "Smart, sustainable and inclusive growth", focuses on the countries' capabilities to improve their innovativeness (European Commission, 2023).

The EU plan targets the individuals' skills which might lead to improving the skills' activation, development, matching, and reducing the mismatch contributing to the increase of creative, knowledge and technologies outputs; however, the main focus is on digital skills and early childhood education. In this context, policymakers should also consider the importance of continuous support for individuals, along with the inclusion of interpersonal and social competencies that might have a higher return in the context of countries with an increased level of digital performance.

Examining this mediation result in the context of the Innovation Diffusion Theory (IDT)'s class of explanation focusing on the individuals' fixed characteristics, people with a higher level of education and developed communication skills contribute to the speed of adopting and creating innovation (Hornik, 2004). Therefore, in an attempt to improve the innovation level and achieve the sustainability objectives, countries should first consider increasing the individuals' skills adequacy, as STEM, interpersonal, and social skills are important drivers of innovation (Brunow et al., 2018; Ciarli et al., 2021; Hsieh et al., 2022). In addition, policymakers should not just focus on improving IO without addressing the primary factors that determine its formation.

Apart from the effect size, the IPMA represents an extension of PLS-SEM, which provides a better understanding of the indicators and latent variables' performance on the key target construct (Ringle and Sarsted, 2016). As depicted in figure no. 3, DSP has the highest performance, contrary to the result obtained by Hung et al. (2023), suggesting a difference between the antecedents of green innovations compared to regular innovations. SM, as expected, had the lowest performance. However, we cannot draw any conclusion on this outcome concerning its impact on innovation, as the indicator had a low loading. Regarding the performance of the latent variables on IO, DP has a total value of 47.575, while SKA has a slightly higher performance (48.461). These results highlight that the indicators used to construct the variable have a positive performance on IO.

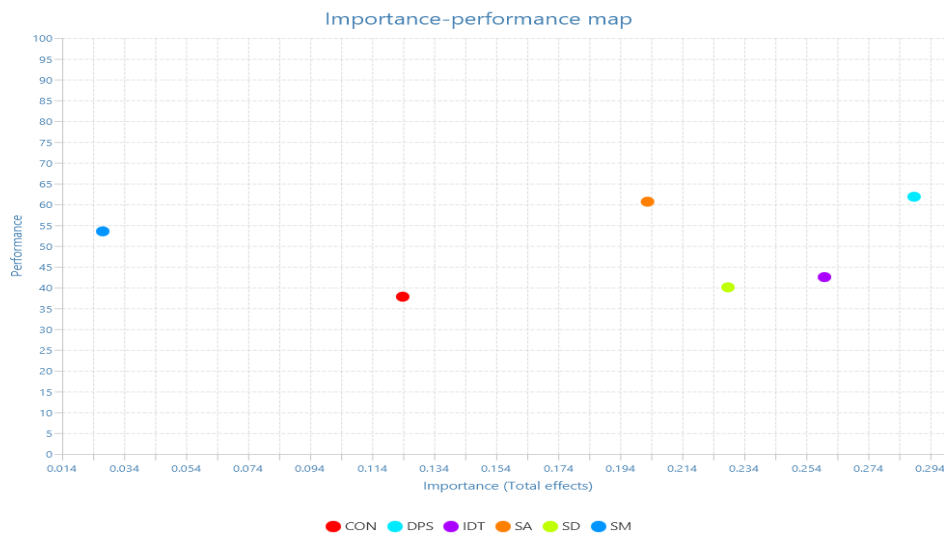


Figure no. 3. Importance-Performance Map of the indicators

Conclusions, limitations and future research directions

The present study investigated the role of the countries' level of digitalisation and skills adequacy as drivers of innovation output. Given the complexity of this coevolution, a deeper understanding of this triad might improve the states' level of competitiveness, advance sustainable economic growth, and provide a better glimpse of the challenges that some business areas might face in the light of Industry 4.0.

To achieve the research's scope, we used a PLS-SEM technique to statistically test the importance and the effect size of the EU countries' level of digital performance on innovation output and skills adequacy. We also conducted a mediation analysis to explore the skills adequacy's role on the innovation output, along with an IPMA to test the indicators' and latent variables' performance on the key target construct. Thus, this research provides a series of useful implications for both policymakers and organisations.

The first conclusion focuses on the significant impact of the countries' digital performance on the innovation output. According to the EU's objective to deliver on the 2030 Agenda, this outcome can be leveraged by policymakers to achieve the objectives related to promoting sustainable industrialisation and innovation. Therefore, companies should use technological advancements to remain competitive and facilitate the creation of innovation.

The second conclusion refers to the positive impact of digital performance on skills adequacy. This outcome has a series of implications for legislators, as, at least for now, this impact is positive, but considering the continuous evolution of digitalisation, individuals will need an adequate level of additional support to continue responding to the labour-market demands. As per the SDG 8, the EU countries must focus on both employment and sustainable economic growth. In this regard, governments should create a series of facilities for organisations to assist individuals in developing the necessary set of skills. Similarly, the positive impact of the skills adequacy on innovation emphasises the need for an appropriate set of STEM, interpersonal, and social skills to foster creative and knowledge and technology outputs. In this context, organisations should emphasise more the need for proper skills systems for both initial and continuous training of the individuals. This outcome targets SDG 4 and SDG 9, highlighting the critical interdependency between ensuring relevant skills for employment and creating innovation.

The third conclusion focuses on the mediating skills adequacy's role in the relationship between digitalisation and innovation. Although there was a statistically significant positive impact between these variables, the overall effect improved. Before this study, the evidence regarding this coevolution was rather theoretical. This result sets the groundwork for future research on the mediating role of the skills adequacy in fostering innovations. The study's outcomes indicate that countries that want to improve their level of innovation should not disregard the human resource dimension, as this represents an important pillar in leveraging digitalisation's benefits and sustainably support economic growth. Thus, even though digitalisation facilitates innovation, the skills adequacy plays a significant role in this coevolution.

This research raises an important question about continuing the positive impact between digitalisation and skills adequacy, at least in the countries with less efficient skills systems. More information on this relationship might assist organisations and policymakers in constructing appropriate strategies when investing in the human resources' development and defining the set of highly recommended skills. As currently the recovery and resilience efforts

are mainly focused on digital competencies and youth employment, more than this approach might be required in addressing the future challenges of the workforce in a highly digitalised environment.

The practical implications of this study relate to how countries, through policymakers, together with the business environment, can contribute to innovation development. By proposing effective strategies to support digitalisation in both public administrations and the private sector, along with an effective framework for skills development to support innovations, countries can contribute to sustainable development and achieve the 2030 Agenda goals.

A limitation of this study is represented by the fact that it did not evaluate the effect of the pandemic on the triad coevolution due to limited data being available for the period 2021-2022, as most of the indexes are based on past-years values. Nevertheless, despite its limitations, the study certainly adds to the understanding of the digitalisation's and skills adequacy's importance as antecedents of innovation. A natural progression of this work is to continue to analyse this coevolution and determine whether the pandemic had a significant role in this relationship. It would also be relevant to investigate the degree to which different EU initiatives contribute to skill improvement and examine the potential gaps between countries.

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