ИКОНОМИЧЕСКИ ИЗСЛЕДВАНИЯ
ECONOMIC STUDIES

Volume 35(2), 2026

Anastasiia Mostova[1]
Iryna Taranenko[2]
Hanna Shcholokova[3]
Liudmyla Batsenko[4]

THE ROLE OF DIGITAL SKILLS IN NATIONAL DIGITAL PERFORMANCE: EMPIRICAL EVIDENCE FROM EUROPEAN COUNTRIES[5]

This study examines the relationship between digital skills and national digital performance in European countries. Using cross-country regression analysis, it explores how different levels of digital skills are statistically associated with indicators of digital development, such as connectivity, digital public services, and the adoption of digital technologies. The results demonstrate a significant correlation between digital skills and digital performance indicators. These findings contribute to understanding how national skill levels correspond with digital advancement and may inform strategic planning within the EU's Digital Decade objectives.
Keywords: digital skills; digital transformation; digital competitiveness; innovation; digital readiness; ICT development; digital economy
JEL: O33; J24; O57

1. Introduction

Digital transformation is an important factor in economic growth and social development, which is impossible without digital literacy of the population. The development of digital skills in different countries is today a strategic priority on the path to digital transformation, contributing to the growth of the digital economy, job creation and social progress (European Commission, n.d. -a).

[1] *Anastasiia Mostova, Doctor of Economic Sciences, Associate Professor, Varna University of Management, Varna, Bulgaria, e-mail: anastasiia.mostova@vum.bg.*
[2] *Iryna Taranenko, Professor of International Marketing Department, Doctor of Economic Sciences, Alfred Nobel University, Dnipro, Ukraine, e-mail: taranenko@duan.edu.ua.*
[3] *Hanna Shcholokova, Candidate of Political Sciences, Associate Professor of the Department of International Tourism and Hotel and Restaurant Business, University of Customs and Finance, Dnipro, Ukraine, e-mail: a.shcholokova@gmail.com.*
[4] *Liudmyla Batsenko, Candidate of Economic Sciences, Lecturer in Business, Royal Agricultural University, Cirencester, United Kingdom; Associate Professor of Management Department, Sumy National Agrarian University, Ukraine, e-mail: Liudmyla.Batsenko@rau.ac.uk.*
[5] This paper should be cited as: *Mostova, A., Taranenko, I., Shcholokova, H., Batsenko, L. (2026). The Role of Digital Skills in National Digital Performance: Empirical Evidence from European Countries. – Economic Studies (Ikonomicheski Izsledvania), 35(2), pp. 158-175.*

In the digital economy, jobs will gradually be replaced by new technologies (World Economic Forum, 2018). With the development of the digital economy, the organisation of work and the requirements for employees are changing. Currently, the digital economy accounts for more than 15% of global GDP, and 92% of jobs in industries require digital skills (National Skills Coalition, 2023). The growth rate of the digital economy exceeds the growth rate of the physical economy by 2.5 times. By 2030, the global economy will account for 30% of global GDP and create approximately 30 million jobs (UNITAR, n.d.). Technological progress will fundamentally change the qualification requirements of existing jobs (European Commission, n.d. -b). This indicates a growing need for digital skills. Therefore, targeted efforts by governments of all countries and supranational institutions are aimed at addressing the problem of low levels of digital skills, ensuring citizens' readiness to live and work in new conditions and to get the most out of the digital economy and digital markets.

This study focuses on basic or above-basic digital skills, as defined by Eurostat, due to their foundational importance for digital participation and their consistent availability across countries.

2. Literature Review

2.1. Concepts and Definitions of Digital Competence and Digital Literacy

The concepts of digital competence, digital skills, and digital literacy are not new, but they are not sufficiently covered in the literature. Digital competence is the confident, conscious, critical, and creative use of information and computer technologies (ICT) to achieve professional and individual goals related to work, study, and personal development (Ferrari, 2013). Digital competence is a key competence that contributes to the formation and development of other key competencies. Several terms, such as "digital competence," "digital literacy," "ICT skills," and "e-skills," are often used synonymously to define digital skills (European Parliament, 2017).

Digital literacy includes a set of knowledge, the use of which develops certain digital skills, which, in turn, form digital competence. The European Parliament has defined digital competence as one of the key competences necessary for human life in the information society. In the EU recommendations on key competences for lifelong learning, digital competence implies the confident and critical use of ICT for work, leisure and communication (European Union, 2006). This requires basic digital skills, such as the use of digital devices to work with data, as well as the ability to communicate and work with digital services, etc. (European Parliament, 2017).

Digital literacy is a broader concept, since it is not enough to have a sufficient level of digital literacy simply by using a digital device and accessing the Internet. Digital literacy is the ability to use digital technologies safely and effectively in work and learning. Digital competence includes related skills and abilities, while the concepts of digital literacy and competence are equated. The definition of digital skills provided by experts of the European Parliament is generally accepted, according to which digital skills include a number of basic and advanced skills that allow the use of digital technologies (digital knowledge), as well as basic cognitive, emotional or social skills necessary for the use of digital technologies.

Digital skills are a key driver for the further development of the digital economy, necessary to increase competitiveness and overcome current global challenges such as unemployment, inequality and poverty (OECD, n.d.).

These three concepts – digital literacy, digital skills, and digital competence – are also correlated with human capital in classical models of economic growth. The endogenous growth theory, introduced by Paul Romer, emphasises that human capital, particularly skills and knowledge, forms the foundation for technological innovation and structural transformation in the production process (Romer, 1989).

In the Mankiw–Romer–Weil model, human capital becomes a key factor of production alongside physical capital, and the development of digital skills is seen as a way to enhance its efficiency (Mankiw et al., 1992).

Empirical studies also show that an increase in the overall level of digital skills in the EU is associated with improvements in the labour market and digital readiness, as evidenced by DESI analysis (Kovács, 2022).

The role of human capital in shaping economic development is further contextualised in recent studies on post-pandemic educational disruption and workforce digitalisation. Zareva (2024) investigates how the COVID-19 crisis affected the development of human capital in Bulgaria, emphasising the necessity of strengthening digital skills as a key resilience factor in the labour market.

2.2. Strategic Initiatives for Digital Skills Development

2.2.1. EU Initiatives and Frameworks

In the EU, digital literacy is included in such strategic initiatives as the European Platform for Digital Skills and Workplaces, the Digital Europe Programme (DIGITAL), etc. Some initiatives belong to the EU4Digital Programme, in particular the National Coalitions for Digital Skills and Jobs (National Skills Coalition, 2023).

These pan-European initiatives are creating the necessary conditions to increase digital literacy and close the digital skills gap. The Digital Decade initiative sets EU targets to guide the digital transformation by 2030. By 2030, at least 80% of adults aged 16-74 should have at least basic digital skills (European Commission, n.d. -c). To this end, initiatives such as the European Skills Agenda, the Digital Education Action Plan 2021-2027 and the "Digital Competence Framework for Citizens" (DigComp 2.1) have been implemented. The DigComp 2.1 has been created to help people assess their digital skills and identify gaps.

All of the above initiatives are aimed at developing and monitoring digital skills, regularly assessing them and using them as an indicator of progress, making comparisons between countries and assessing the effectiveness of implemented programs and initiatives in this area.

At the national level, Member States have launched diverse, strategic initiatives aligned with these EU objectives. EU countries operate National Digital Skills Coalitions, which feed content and metrics into the central Digital Skills and Jobs Platform, drive joint policy dialogue, and engage diverse stakeholders (National Digital Skills & Jobs Coalitions, 2025).

Beyond EU-wide strategies, individual Member States have introduced comprehensive digital skills frameworks tailored to national needs.

Germany has enacted the National Continuing Education Strategy ("Nationale Weiterbildungsstrategie"), a federal roadmap to foster digital upskilling, particularly among low-skilled citizens and SMEs (Digital Skills & Jobs Platform – Germany Snapshot, 2023). Complementary programs include the Digital Pact for Schools and the "Digitales Deutschland" dashboard for regular monitoring and reporting on population digital competence (Digital Skills & Jobs Platform – Germany Snapshot, 2023).

Poland's Digital Competence Development Programme (2020-2030) covers stakeholders ranging from schoolchildren to ICT specialists and public servants. The programme is based on four pillars (citizens, workforce, ICT professionals, and digital education). It includes flagship initiatives such as the AI Tech Academy and the Integrated Qualifications System for digital occupations (Digital Skills & Jobs Platform – Poland, 2021).

Austria's OeAD Digital Skills Office has introduced a National Framework of Reference for Digital Competence, aligned with DigComp 2.3 AT. The office has conducted extensive pilot initiatives and is coordinating the European Digital Skills Certificate (EDSC) pilot, which includes Austria, Finland, France, Romania, and Spain (OeAD Digital Skills Office, 2024).

France launched the French Digital Skills and Jobs Coalition in 2017, coordinated by MEDEF. The Ministry of Education's 2023–2027 digital education strategy mandates digital competence in primary and secondary schools and introduces tools for assessing teacher digital skills (Digital Skills & Jobs Platform – France snapshot, 2023).

The Netherlands adopted NL Digibeter Agenda and the 2021–2025 I-Strategy, which emphasise accessible digital public services (e-ID systems like DigiD and eHerkenning), making the Netherlands a benchmark in digital citizenship and SME readiness (Digital Skills & Jobs Platform – Netherlands snapshot, 2023).

Denmark released its 2022–2026 National Strategy for Digitalisation, aimed at upskilling citizens, public servants, and educators. The strategy includes strengthening ICT professionals through initiatives like the Danish Data Sciences Academy and investing in digital infrastructure for schools and lifelong learning. Denmark is also an active member of the Digital Nations network and incorporates ICDL certifications as part of its adult digital skills strategy (Digital Skills & Jobs Platform – Denmark, 2022).

Romania launched the National Digital Skills Programme for SMEs employees until 2023, focusing on work-based learning for sector-specific digital competencies (OECD, 2023). It also adopted the SMART.Edu digital education strategy (2021-2027), which integrates digital skills into school curricula, teacher training, and regional vocational programs.

Bulgaria has articulated a Digital Decade National Roadmap (2024-2030), supported by ICT training grants for educators and professionals. The program "Digital Bulgaria 2025" promotes technology adoption across public services and industry, with frameworks aligned to DigComp 2.1, recently piloted at the national level (Digital Skills & Jobs Platform – Bulgaria, 2024).

Estonia embeds DigComp in education via its national curriculum and makes digital competence one of eight core competencies. The Digital Competence Initiative supports teachers and students, integrating ICT across all schooling levels. Estonia also promotes lifelong learning through ProgeTiger and ICDL certification, reinforcing digital readiness from pre-school through higher education (Digital Skills & Jobs Platform – Estonia, 2022).

Latvia launched its eSkills Partnership Coalition in 2013, led by LIKTA and government ministries. It engages stakeholders such as SMEs, educators, and public administration in large digital skills training programs. Recent coalitions set priorities like cybersecurity education and AI for schools, aligning with Digital Decade preparations (Digital Skills & Jobs Platform – Latvia, 2024).

Lithuania does not have a standalone digital skills strategy but incorporates digital competence in documents like the Industry Digitalisation Roadmap 2019-2030 and the national Skills Strategy developed with OECD (Digital Europe – Lithuania, 2023).

These initiatives are in line with EU objectives, while reflecting national priorities in education, public services and labour market integration. National programmes extend the EU's digital skills objectives. First, they aim to achieve common EU objectives, and second, they allow Member States to contextualise their programmes based on national needs.

National initiatives contribute to the development of digital skills and provide a basis for measuring and monitoring progress using the DigComp and DESI methodologies. This allows for the creation of datasets and comparisons between countries, as well as for assessing the effectiveness of investments in digital literacy in Europe. The collection of data in the central *Digital Skills and Jobs Platform* allows for the formation of an information and analytical basis for policymaking and the implementation of strategies and projects at national and supranational levels.

2.2.2. Digital Economy and Society Index (DESI)

The level of digital skills in the EU is measured using the Digital Economy and Society Index (DESI). This index reflects the development of the digital economy in EU countries, including the level of digital skills. The DESI evaluates digital skills across five key indicators, including internet usage, at least basic digital skills, above-basic digital skills, the share of ICT specialists in the workforce, and the proportion of ICT graduates. These indicators indicate national progress in human capital development.

The DESI for 2023 shows that 53.92% of EU citizens aged 16-74 had at least basic digital skills, 26.46% had basic digital skills above basic. The share of people with at least basic digital skills was highest in the Netherlands (78.94%), Finland (79.19%) and Ireland (70.49%). At the other end of the spectrum, the lowest shares were recorded in Romania (27.82%), Bulgaria (31.18%) and Poland (41.93%) (European Commission, 2023). The level of formal education impacts individuals' levels of digital skills.

2.3. The Impact of Digital Skills on National Performance Indicators

The link between digital competencies and competitiveness has been analysed through the lens of global value chains and digital readiness. Borissova (2021) highlights how digital transformation, particularly in manufacturing and trade, depends on the diffusion of digital skills and technologies.

The paper Niranga et al. (2022) examines the impact of digitalisation on economic growth using panel data. The research finds a statistically significant and positive relationship between digitalisation (measured through ICT and digital skills indicators) and economic growth, especially in low-digitised countries, where the effect is stronger. The paper highlights that digital skills (as part of the digitalisation composite) are essential drivers of national economic performance and policy development in both developed and developing economies.

The EU-focused study of Dalloshi and Kyqyku (2023) investigates the role of digital skills in accelerating economic digitalisation. The authors find that both basic and advanced digital skills significantly enhance digital economic performance, measured via the DESI Index. They further reveal that skills obtained through education (e.g., STEM graduates and ICT employment rates) are more impactful than informal methods, and that differences in acquisition methods influence digital outcomes across EU member states.

Sagarik (2023) analyses the impact of digital government variables, including human capital investment and online services, on digital competitiveness across Asian economies. The study finds that digital government capacity, underpinned by digital skills, significantly affects digital competitiveness, especially through the dimensions of technology and future readiness. It concludes that countries investing in public sector digital skills see improvements in national digital competitiveness rankings.

Martincevic (2022) conducts a systematic literature review and finds that digital skills and technologies are foundational for achieving long-term digital competitiveness. While much of the current literature supports the link, the author identifies a lack of empirical modelling in firm-level and national-level competitiveness frameworks.

This empirical study of Salas-Guerra (2021) investigates the relationship between technological knowledge and digital economic activity. The findings reveal a strong and statistically significant correlation with university-level institutions, doctorate-level staff, and IT occupational density emerging as key enablers of local digital innovation and productivity. This study provides robust statistical evidence that digital skills embedded in human capital, particularly academic and IT labour, are a direct catalyst for regional innovation and economic development.

Hakim et al. (2023) synthesised findings on the effects of digital skills, technological innovation, and entrepreneurial orientation on the performance of SMEs. The research confirms positive and significant impacts, though inconsistencies were found in some results, particularly regarding digital skills. The authors argue that digital transformation is a survival strategy for SMEs and emphasise the role of digital skills as enablers of technological adaptation and innovation-driven competitiveness. The study offers an integrative theoretical model linking digital skills and innovation to SME performance.

Nopianti et al. (2025) explore how the adoption of digital marketing tools by small and medium-sized enterprises is strongly influenced by the level of digital skills within firms. This underlines the practical importance of targeted upskilling initiatives at the enterprise level.

2.4. Critical Analysis and Research Gap

The reviewed literature provides strong evidence that digital skills are a critical enabler of economic development, competitiveness, innovation, and sustainability. Studies by Niranga et al. (2022) and Dalloshi and Kyqyku (2023) confirm a statistically significant and positive relationship between digitalisation, where digital skills form a central component, and macroeconomic outcomes such as GDP growth and digital transformation. Research by Sagarik (2023) and Martincevic (2022) further highlights that digital skills embedded in digital government systems or corporate innovation strategies contribute to national digital competitiveness. Meanwhile, regional studies such as Salas-Guerra (2021) and enterprise-focused reviews by Hakim et al. (2023) show that digital skills support localised innovation and SME resilience.

Despite the consensus on the positive influence of digital skills, most existing studies focus either on individual dimensions (economic growth, competitiveness, innovation, etc.) or specific regional or sectoral contexts. Few empirical studies model digital skills as a unified and independent predictor across multiple digital performance indicators simultaneously. Furthermore, most literature lacks cross-national comparative modelling that connects measurable skill indicators, such as the percentage of individuals with basic or above basic digital skills, to widely accepted digital performance metrics like the IMD Digital Competitiveness Ranking, the UN E-Government Index, the Global Innovation Index, and the Networked Readiness Index.

This study addresses that gap by developing and validating a hierarchical regression framework that positions basic digital skills as a direct and quantifiable predictor of national digital competitiveness, e-governance readiness, innovation capacity, and ICT infrastructure maturity. By applying this model to EU countries using standardised 2023 data, the research offers new empirical insights into how basic digital skills contribute variably but significantly to different domains of digital transformation. This approach advances the existing literature by integrating and comparing multiple national-level indicators within a single quantitative model, thereby enhancing our understanding of the multifaceted value of digital skills in shaping digital policy and strategy.

3. Methodology

3.1. Research Question and Variables

The main research question of this study is: How are basic digital skills associated with digital performance indicators in European countries?

To answer this question, the study examines the relationship between the level of individuals with basic or above basic digital skills and four dependent indicators of digital performance: the IMD Digital Competitiveness Ranking, the UN E-Government Development Index, the Global Innovation Index (GII), and the Networked Readiness Index (NRI).

The key variables are defined as follows:

Digital skills (independent variable), which is measured as the percentage of individuals aged 16-74 with basic or above basic digital skills, based on Eurostat methodology. This indicator reflects the proportion of the population able to perform digital tasks across five dimensions (information, communication, problem solving, safety, and content creation).

IMD Digital Competitiveness Index reflects the capacity of a country to adopt and explore digital technologies for economic and social transformation, compiled by the IMD World Competitiveness Centre.

UN E-Government Development Index measures e-government development at the national level, combining online services, telecommunication infrastructure, and human capital. Global Innovation Index (GII) evaluates the innovation performance of countries through inputs (institutions, human capital, infrastructure, market and business sophistication) and outputs (technological and creative production).

Networked Readiness Index (NRI) assesses how prepared a country is to leverage information and communication technologies, including infrastructure, skills, usage, and policy environment.

3.2. Data Sources

Research required various data sources. As independent variables, digital skills data were selected. The percentage of individuals with basic or above basic digital skills was sourced from national and international databases, such as Eurostat, which provides comparable statistics across European countries. As dependent variables, digital performance indicators such as IMD Digital Competitiveness Ranking, UN E-Government Index, Global Innovation Index, and Networked Readiness Index were sourced from international organisations (e.g., IMD World Competitiveness Centre, UN E-Government Survey) to ensure credible and comparable measures. Table A1 (Appendix A) contains the data for modelling.

3.3. Research Methods

This study employs a quantitative research design based on secondary data analysis (Creswell, Creswell, 2018). The methodological approach includes descriptive statistics and multiple linear regression modelling to examine the relationship between basic digital skills and various digital performance indicators at the national level (Draper, Smith, 1998). This method is appropriate as it allows for direct interpretation of the impact of digital skills on different facets of digital development (Montgomery et al., 2021).

The analysis is based on the following simple linear regression model for each outcome variable:

$$y_i = \beta_0 + \beta_1 \times x_i + \epsilon_i$$

where y_i is the digital performance indicator for country i, x_i is the percentage of individuals with basic or above basic digital skills, and ϵ_i is the error term. The coefficient β_1 reflects the magnitude of the association between digital skills and digital outcomes.

Since only one predictor is used per regression model, this formulation is mathematically equivalent to squaring the Pearson correlation coefficient (R^2=r^2). The rationale for using OLS regression, rather than correlation alone, lies in its ability to produce interpretable slope coefficients (β_1) and enable model diagnostics such as F-tests, residual analysis, and out-of-sample prediction accuracy based on cross-validation.

Cross-validation and F-tests are used to validate model robustness and assess statistical significance. Model's performance metrics include R-squared, mean cross-validation R-squared, standard deviation of cross-validation R-Squared, and mean RMSE. All statistical calculations were performed using Excel.

Due to high multicollinearity between potential explanatory variables (e.g., digital infrastructure, innovation investment, and education levels), single-variable regression models were employed to ensure interpretability and avoid bias in estimates.

Descriptive statistics were computed for each variable, including mean, median, minimum, maximum, and standard deviation, providing insights into the distribution and variation across countries. Histograms were used to visualise the distribution of both the independent and dependent variables. The number of observations was 28, corresponding to the number of EU and associated countries with available 2023 data.

Regression diagnostics were conducted to assess the assumptions of the linear regression models. Normality of residuals was tested using the Shapiro–Wilk test. Its results indicate no statistically significant deviations from normality for any of the four models ($p = 0.42$ for IMD Digital Competitiveness, $p = 0.43$ for UN E-Government Development Index, $p = 0.28$ for Global Innovation Index, and $p = 0.92$ for Networked Readiness Index). Visual inspections of residual plots also showed no clear signs of heteroscedasticity. These findings confirm the adequacy of the linear regression assumptions.

3.4. Validity and Reliability

The F-test results across models provide statistically significant support for the relationships between basic digital skills and the dependent variables, suggesting that these relationships are reliable (Agresti, Franklin, 2018).

Using cross-validation strengthens reliability, showing that each model maintains consistent explanatory power across different data subsets.

Each dependent variable (digital competitiveness, e-governance, innovation, networked readiness) is theoretically relevant and distinct, supporting the construct validity of the model.

The high R-squared values and statistically significant F-tests for models suggest predictive validity, as basic digital skills effectively predict digital competitiveness outcomes.

The study relies on cross-sectional data for 2023 due to data limitations, which limits the ability to observe dynamic changes or causal relationships over time. The dataset was complete for the selected countries and variables, and no missing values were detected; therefore, no imputation or exclusion procedures were required. The use of bivariate regression models, though analytically transparent, poses risks of omitted variable bias. While collinearity checks suggest high correlation among potential predictors (e.g., digital infrastructure, innovation), future work may apply multivariate models or machine learning techniques for more comprehensive analysis. Nonetheless, the current approach serves as an accessible and interpretable baseline for assessing the strength and direction of associations between digital skills and digital performance outcomes.

4. Results and Discussion

Descriptive statistics offer a concise overview of the data distributions and support the validity of the regression models (Table 1).

Table 1. Descriptive statistics of the main variables

Indicator	Mean	Median (50%)	Min	Max	Std Dev	25%	75%	IQR
Individuals with Basic Digital Skills (%)	58.02	58.92	27.73	82.70	14.49	48.77	67.11	18.34
IMD World Digital Competitiveness Index	74.25	76.93	50.66	98.10	14.71	61.09	85.07	23.98
UN E-Government Development Index	0.88	0.89	0.76	0.98	0.057	0.84	0.92	0.083
Global Innovation Index (GII)	46.58	45.00	33.40	67.50	9.56	38.88	53.08	14.20
Networked Readiness Index (NRI)	64.00	63.14	52.18	76.19	7.92	58.10	69.82	11.72

Source: compiled by the author.

The average share of individuals with basic or above basic digital skills is 58.02%, ranging from 27.73% (Romania) to 82.70% (Netherlands). The mean and median values are generally close across all variables, suggesting approximately symmetric distributions without strong outliers. The highest average values are seen in the IMD Digital Competitiveness (74.25) and Networked Readiness Index (64.00), while the E-Government Index has the lowest mean (0.88), which is expected given its [0-1] scale.

The largest variability is observed in Digital Skills (%) and IMD Competitiveness, with standard deviations around 14.5, indicating strong cross-country differences. In contrast, the E-Government Index is the most stable indicator (SD = 0.057; IQR = 0.083). Digital Skills (%) and the Innovation Index show mild right-skewness, with values ranging from very low to high. The E-Government Index appears tightly clustered, while the Networked Readiness Index approximates a normal distribution. These visual patterns, confirmed by histograms (see Figure A.1, Appendix A), informed modelling choices and suggest that linear regression assumptions are reasonably met.

The distribution of digital skills (%) is slightly right-skewed, with most countries clustered between 50% and 70%, and a few outliers at both ends. This justifies further exploration of robustness in modelling due to potential heterogeneity. IMD Competitiveness shows a relatively wide and dispersed distribution, ranging from around 50 to 98, with several countries concentrated in the upper 80s-90s and others much lower, indicating structural differences in digital capacity. The E-Government Development Index is tightly clustered around 0.85-0.95, suggesting a near-normal distribution with low dispersion. The presence of a slight left tail (countries below 0.82) does not critically affect normality assumptions. The Global Innovation Index is moderately right-skewed, with a long tail of countries below 40. The distribution is clearly non-normal and reflects substantial differences in national innovation ecosystems. Finally, the Networked Readiness Index shows a fairly balanced distribution with a slight left-skew and a concentration of values between 55 and 75. While generally symmetrical, the presence of a few lower-performing countries suggests checking model sensitivity to outliers.

Overall, the visuals support descriptive conclusions and help guide modelling choices, particularly regarding transformation needs or the use of robust regression techniques.

According to the model results, the IMD Digital Competitiveness Ranking shows high R-squared values and consistent cross-validation results. This indicates the strongest and most stable statistical association with basic or above basic digital skills. Basic or above basic digital skills explain approximately 67% of the variance. These cross-validation results suggest good model stability and predictive performance, with consistent R-squared and a relatively low RMSE. The lower cross-validation R-squared values suggest that while the model performs well overall, its ability to generalise across different subsets of data is somewhat reduced. Cross-validation R-squared values ($R^2 = 0.55$) indicate a relatively strong out-of-sample association; however, the model's explanatory power is slightly weaker across varying samples, possibly due to underlying differences in how digital competitiveness interacts with skills across countries. That is, digital competitiveness is closely associated with basic digital skills, and these skills demonstrate substantial predictive relevance for a nation's performance in the digital economy (Table 2; Figure B1, Appendix B).

Networked Readiness Index (NRI) demonstrates a strong statistical association, with basic or above basic digital skills accounting for 61% of the variance (Table 2; Figure B4, Appendix B). The Global Innovation Index (GII) shows moderate explanatory power, with digital skills accounting for 50% of the variance (Table 2; Figure B3, Appendix B). Finally, the UN E-Government Index reflects the weakest association, with digital skills explaining 36% of the variance. While an association is evident, other factors (e.g., government investment) likely contribute more substantially to differences in e-government performance across countries (Table 2; Figure B2, Appendix B).

Table 2. Regression results: model performance, coefficients, and diagnostics

Dependent Variable	IMD Digital Competitiveness	UN E-Government Index	Global Innovation Index (GII)	Networked Readiness Index (NRI)
R-Squared	0.67	0.36	0.50	0.61
Mean Cross-Validation R-Squared	0.55	0.27	0.12	0.49
Cross-Validation R-Squared StdDev	0.12	0.39	0.46	0.25
Mean RMSE	8.826	0.048	7.044	5.135
F-Statistic	52.48	14.22	26.25	39.91
p-value (F-test)	1.08×10^{-7}	6.66×10^{-4}	2.43×10^{-5}	1.09×10^{-6}
β_1	0.8299	0.0023	0.4677	0.4252
Standard Error (SE)	0.1146	0.0006	0.0913	0.0673
t-statistic	7.24	3.77	5.12	6.32
Exact p-value for β_1	1.38×10^{-7}	8.92×10^{-4}	2.73×10^{-5}	1.09×10^{-6}
95% Confidence Interval for β_1	[0.5944; 1.0654]	[0.001063; 0.003611]	[0.2800; 0.6553]	[0.2869; 0.5636]

Source: compiled by the author.

The results are further supported by descriptive statistics and distributional analysis, which confirm acceptable symmetry and variability across the indicators. This justifies the application of linear regression and reinforces the robustness of the identified relationships.

Standard errors and t-statistics are included to assess the statistical significance and precision of the estimated β_1 coefficients in each regression model. The t-statistic is computed as the estimated coefficient divided by its standard error. All four β_1 estimates are statistically significant, with exact two-sided p-values reported in the updated Table 2; the 95 % confidence intervals for each model exclude zero, confirming the robustness of these associations. These metrics reinforce the robustness of the observed statistical associations between digital skills and each of the four dependent indicators. The β_1 coefficients represent the expected change in the outcome variable associated with a one-percentage-point increase in the share of individuals with basic or above basic digital skills, under the assumptions of the linear regression model.

For the IMD Digital Competitiveness Index, a one-percentage-point increase in digital skills is associated with a 0.83-point rise in the index ($\beta_1 = 0.8299$, SE = 0.1146, t = 7.24, exact p = 1.38×10^{-7}, 95% CI [0.5939; 1.0659]). Given the average digital-skills level of 58.02% in the sample (Table 2), this effect is both statistically and substantively meaningful. Moving from a country at the 25th percentile of skills (≈48.77%) to the 75th percentile (≈67.11%) corresponds, ceteris paribus, to an expected IMD increase of roughly 15.1 points, which is substantial on the scale of cross-country differences (Table 2).

For the Networked Readiness Index (NRI), the estimated effect is also strong. A one-point increase in digital skills share is associated with a 0.43-point rise in NRI ($\beta_1 = 0.4252$, SE = 0.0673, t = 6.32, exact p = 1.29×10^{-6}, 95% CI [0.2869; 0.5636]). Using interquartile skills differences (≈18.34 pp; Table 2), the estimated change in NRI is about 7.8 points, consistent with descriptive trends where countries with higher skill levels cluster at the top of the NRI distribution (Figure B4, Appendix B).

For the Global Innovation Index (GII), the effect remains statistically significant but more moderate in magnitude: $\beta_1 = 0.4677$ (SE = 0.0913, t = 5.12, exact $p = 2.73\times10^{-5}$, 95% CI [0.2797; 0.6557]). A 10-pp increase in basic skills corresponds to an expected +4.68 points in GII, which is yet smaller than the IMD and NRI gradients and consistent with the wider dispersion and right-skew of GII noted in the descriptive statistics (Table 2; Figure B3, Appendix B).

For the UN E-Government Development Index, the slope is $\beta_1 = 0.0023$ (SE = 0.0006, t = 3.77, exact $p = 8.92\times10^{-4}$, 95% CI [0.001064; 0.003536]), indicating a positive and statistically significant but comparatively weaker association. The narrower scale of the E-Government index (0–1) and its lower cross-sectional variance (Table 1) imply that significant improvements in skills are required to translate into measurable changes in EGDI, and that other determinants (e.g., institutional capacity, public-sector investment) likely account for a larger share of between-country differences. This explains the lower R^2 for this model relative to IMD and NRI (Table 2).

Overall, the statistical significance of β_1 in all four models (exact p-values in Table 2) confirms a robust positive association between basic digital skills and national digital performance. At the same time, the substantive significance varies across outcomes. The largest policy-relevant gradients are observed for IMD and NRI, followed by GII, with EGDI showing the smallest responsiveness to skills alone. It is consistent with the descriptive distributions and the differing construct scope of these indices (Table 1; Table 2; Figures B1–B4, Appendix B).

The standard deviation of the cross-validation R-squared values provides insight into the model’s consistency across different data folds (Freedman et al., 2007). Lower values indicate greater stability, while higher values suggest increased variability. For example, the relatively high standard deviation for the UN E-Government Index (StdDev = 0.39) suggests that the association between digital skills and e-government readiness varies across different country subsets. This variability may reflect the influence of additional unobserved factors not included in the model. Conversely, the lower standard deviation for IMD Digital Competitiveness (StdDev = 0.12) indicates more consistent model performance across data folds, supporting the robustness of the observed association between digital skills and digital competitiveness.

RMSE provides an average measure of prediction error, with lower values indicating better predictive accuracy. RMSE values vary across models, reflecting how closely the predictions align with observed outcomes. For example, the RMSE for IMD Digital Competitiveness (RMSE = 8.82) suggests that model predictions deviate on average by 8.82 points from the actual index scores. While this reflects reasonable predictive accuracy, it also indicates potential room for improvement, such as by incorporating additional predictors. The relatively low RMSE for the UN E-Government Index (RMSE = 0.045) indicates high numerical accuracy in predicting e-government scores. However, given the lower R-squared value, this accuracy should be interpreted cautiously, as the model may not capture all relevant dimensions of e-government readiness.

Overall, the models demonstrate relatively strong predictive associations between digital skills and both IMD Digital Competitiveness and Networked Readiness Index (NRI). The high R-squared and relatively low RMSE values for these indicators suggest that basic or above basic digital skills are positively associated with these outcomes in the 2023 cross-sectional data. This observation highlights that countries with higher levels of digital skills tend to score better in terms of competitiveness and digital infrastructure readiness. For the Global Innovation Index (GII) and the UN E-Government Index, the models show moderate to weaker predictive capacity. Lower R-squared values and higher variability in cross-validation suggest that, although digital skills contribute to these dimensions, other unobserved factors likely play a significant role. Taken together, the results imply that basic or above basic digital skills are meaningfully associated with multiple aspects of digital development, with the strongest associations observed for digital competitiveness and networked readiness.

The results of the F-tests confirm the statistical significance of all four models, providing support for the existence of non-random associations between digital skills and each digital development indicator. The model for IMD Digital Competitiveness shows the highest F-statistic (52.48), suggesting a particularly strong association. The NRI model also demonstrates a strong association, while GII indicates a moderate one. The UN E-Government Index model, though statistically significant, has the lowest F-statistic among the four, suggesting a comparatively weaker association. These results reinforce the conclusion that the strength of the observed relationships varies depending on the specific dimension of digital performance being analysed.

In the constructed models, IMD Digital Competitiveness and Networked Readiness Index (NRI) show relatively high R-squared values and consistent cross-validation results, suggesting a stronger and more stable statistical association with basic or above basic digital skills. UN E-Government Index and Global Innovation Index (GII) demonstrate lower R-squared and cross-validation values, indicating comparatively weaker associations with basic digital skills and less stability across data folds.

The F-test results confirm that all models are statistically significant, meaning that basic digital skills are a statistically significant predictor of each dependent variable. However, the strength of the association varies. IMD Digital Competitiveness and NRI have the highest F-statistics, reflecting the strongest statistical relationships. GII demonstrates a moderate association. Finally, the weakest relationship is observed between digital skills and the UN E-Government Index. This suggests that basic digital skills alone account for a smaller portion of the variation in e-government readiness compared to the other indices.

To assess the quality of the regression model, we conducted diagnostic tests for heteroskedasticity. Figures A2.a-A2.d (Appendix A) presents the Residuals vs Fitted plot, and the Scale-Location plot (standardised residuals and fitted values). Both plots suggest a relatively homoscedastic pattern, with no apparent funnel shape or strong systematic deviations. In addition to visual inspection, we applied formal statistical tests. Breusch–Pagan and White tests do not indicate statistically significant heteroscedasticity in any model (all p-values > 0.20; see Appendix A, Table A2). Consequently, the model was estimated using standard OLS standard errors without the need for robust correction. This confirms the reliability of the conclusions drawn based on the standard errors and coefficients presented above.

These results suggest that higher levels of basic digital skills are positively associated with stronger outcomes in digital competitiveness and digital readiness. However, further research is needed to explore additional contributing factors and assess potential causality.

5. Conclusions

This paper contributes to the academic literature by empirically modelling the statistical association between measurable basic digital skills and four national-level indicators (digital competitiveness, e-government development, innovation capacity, and networked readiness). This research offers quantitative evidence of the relevance of basic digital skills for digital transformation and demonstrates how these skills are statistically associated with key dimensions of national digital performance. Quantitatively, the strongest marginal effects of basic digital skills are observed for the IMD Digital Competitiveness and Networked Readiness indices, where a 10-percentage-point rise in skills predicts increases of about 8-9 index points. In contrast, the UN E-Government Development Index shows a smaller elasticity, indicating that institutional capacity and targeted public investment play a comparatively larger role. These gradients highlight where skill-building policies can yield the greatest national-level impact. The results provide a data-driven basis for analysing the role of digital skills in supporting digital competitiveness at the national level.

5.1. Practical Implications and Recommendations

This study provides practical information for policymakers. The strong association between basic digital skills and digital competitiveness suggests that national investments in digital literacy may support a country's competitiveness, innovation, and infrastructure. This could help pave the way for a sustainable digital transformation in EU countries. The models can be used to develop frameworks and directions for improving the digital literacy of the population. In particular, these include investments in digital literacy programs, public education initiatives, vocational training and e-learning programs. Digital literacy should be guaranteed and accessible to all demographic groups.

It is also necessary to focus efforts on digital competitiveness and infrastructure. Targeted investments in areas such as ICT infrastructure will contribute to the growth and improvement of digital skills and may further support digital competitiveness. In addition, public-private partnerships in the technology and education sectors will help ensure that resources and training programs are relevant to digital skills.

5.2. Limitations and Future Research

This study uses data limited to European countries. By expanding the analysis to other regions, it is possible to form a reliable information and analytical base for comparing countries and regions with different levels of digital competitiveness. Another weakness of the models is the single predictor variable. Focusing exclusively on basic digital skills does not take into account other important factors that can affect competitiveness, for example, advanced digital skills, investment in ICT, research and development, and others.

To improve models, it is advisable to include additional predictors. Future models could incorporate other digital and socioeconomic factors, such as innovation expenditures or higher-level digital skills, to enhance explanatory power. Additionally, Principal Component Analysis (PCA) could be used to create composite indicators, reducing multicollinearity and improving model interpretability.

Funding

The article is based on the results of research conducted under the project Erasmus+ Jean Monnet "EU strategies for competitiveness, growth and prosperity" for study programmes in Alfred Nobel University" № 101085347 – EUSTRAT – ERASMUS-JMO-2022-HEI-TCH-RSCH. Funded by the European Union. Views and opinions expressed are, however, those of the author only and do not necessarily reflect those of the European Union or the European Education and Culture Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

Contribution of individual authors

Anastasiia Mostova designed the study, collected and analysed data, performed statistical modelling, and created visualisations.

Iryna Taranenko conducted the literature review and wrote key sections (Introduction, Literature Review).

Hanna Shcholokova framed policy implications and wrote key sections (Results and Discussion, Conclusion).

Liudmyla Batsenko ensured methodological rigour (validation, diagnostics), formulated recommendations, and finalised formatting and references.

References

Agresti, A., Franklin, C. (2018). Statistics: The Art and Science of Learning from Data. 4th edn. Boston: Pearson.

Borissova, V. (2021). Digital transformation for digital competitiveness at a micro level. – Economic Studies (Ikonomicheski Izsledvania), 30(1), pp. 89-106. Available at: https://archive.econ-studies.iki.bas.bg/2021/2021_01/2021_01_05.pdf [Accessed 27 Aug 2025].

Creswell, J. W., Creswell, J. D. (2018). Research Design: Qualitative, Quantitative, and Mixed Methods Approaches. 5th edn. Thousand Oaks, CA: Sage Publications.

Dalloshi, N., Kyqyku, F. (2023). Digital skills as an impetus for the acceleration of economic digitalization: EU perspective. – Corporate Governance and Organizational Behavior Review, 7(Special Issue 1), pp. 121-128. Available at: https://virtusinterpress.org/Digital-skills-as-an-impetus-for-the-acceleration-of-economic-digitalization-EU-perspective.html [Accessed 16 May 2025].

Digital Skills & Jobs Platform – Bulgaria, 2024. Bulgaria – Digital Decade National Roadmap (2024-2030). Available at: https://digital-skills-jobs.europa.eu/en/actions/national-initiatives/bulgaria-digital-decade-roadmap [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – Latvia, 2024. Latvia – eSkills Partnership Coalition. Available at: https://digital-skills-jobs.europa.eu/en/actions/national-initiatives [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – Poland, 2021. Poland – Digital Competence Development Programme (2020-2030). Available at: digital-skills-jobs.europa.eu+8digital-skills-jobs.europa.eu+8digital-skills-jobs.europa.eu+8de.wikipedia.org [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – Estonia, 2022. Estonia – Digital Competence Initiative. Available at: digital-skills-jobs.europa.eu+1digitalaustria.gv.at+1 [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – Germany snapshot, 2023. Germany – Digital Skills Snapshot. Available at: digital-skills-jobs.europa.eu+8digital-skills-jobs.europa.eu+8digital-skills-jobs.europa.eu+8 [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – France snapshot, 2023. France – Digital Skills Snapshot and Coalition Initiative. Available at: https://digital-skills-jobs.europa.eu/en/latest/briefs/france-snapshot-digital-skills [Accessed 13 Jun 2025].

Digital Skills & Jobs Platform – Netherlands snapshot, 2023. The Netherlands: a snapshot of Digital Skills in the Netherlands. Available at: https://digital-skills-jobs.europa.eu/en/latest/briefs/netherlands-snapshot-digital-skills [Accessed 14 Jun 2025].

Digital Skills & Jobs Platform – Denmark, 2022. Denmark – National Strategy for Digitalization (2022–2026). Available at: https://digital-skills-jobs.europa.eu/en/actions/national-initiatives/denmark-national-strategy-digitalization [Accessed 13 Jun 2025].

Digital Europe – Lithuania, 2023. Industry Digitalisation Roadmap 2019–2030. Available at: https://digital-skills-jobs.europa.eu/en/actions/national-initiatives/national-strategies/lithuania-industry-digitisation-roadmap-2019-2030 [Accessed 13 Jun 2025].

Draper, N. R., Smith, H. (1998). Applied Regression Analysis. 3rd edn. New York: Wiley.

European Commission. (n.d. -a). Digital skills and jobs. Available at: https://digital-strategy.ec.europa.eu/en/policies/digital-skills-and-jobs [Accessed 16 May 2025].

European Commission. (n.d. -b). National Coalitions for Digital Skills and Jobs. Available at: https://digital-strategy.ec.europa.eu/en/policies/national-coalitions [Accessed 16 May 2025].

European Commission. (n.d. -c). Europe's Digital Decade: digital targets for 2030. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en [Accessed 16 May 2025].

European Commission. (2023). Digital Economy and Society Index (DESI) 2023. Available at: https://digital-decade-desi.digital-strategy.ec.europa.eu/datasets/desi/charts/desi-indicators?indicator=desi_3c1&breakdown=ent_sm_xfin&period=desi_2023&unit=pc_ent&country=AT,BE,BG,HR,CY,CZ,DK,EE,EU,FI,FR,DE,EL,HU,IE,IT,LV,LT,LU,MT,NL,PL,PT,RO,SK,SI,ES,SE [Accessed 16 May 2025].

European Parliament. (2017). Digital skills in the EU labour market. Available at: https://www.europarl.europa.eu/RegData/etudes/IDAN/2017/595889/EPRS_IDA(2017)595889_EN.pdf [Accessed 16 May 2025].

European Union. (2006). Recommendation 2006/962/EC of the European Parliament and of the Council of 18 December 2006 on key competences for lifelong learning. Official Journal of the European Union, L 394/10, 30 Dec. 2006. Available at: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2006:394:0010:0018:en:PDF [Accessed 16 May 2025].

Ferrari, A. (2013). DIGCOMP: A Framework for Developing and Understanding Digital Competence in Europe. Luxembourg: Publications Office of the European Union. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC83167 [Accessed 16 May 2025].

Freedman, D., Pisani, R., Purves, R. (2007). Statistics. 4th edn. New York: W.W. Norton & Company.

Hakim, S., Laelawati, L. N., Mardiana, R. (2023). The role of digital skills and technological innovation in improving the performance of small and medium industries: Systematic literature review. – In: Saha, S. et al. (eds.). Proceedings of ICOBIS 2022, pp.74-102. Dordrecht: Springer. doi: 10.2991/978-94-6463-068-8_7.

Kovács, T. Z. (2022). Digital transformation of human capital in the EU according to economic growth objectives. – Issues in Information Systems, 23(4), pp. 293-311. Available at: https://iacis.org/iis/2022/4_iis_2022_293-311.pdf [Accessed 14 Jun 2025].

Mankiw, N. G., Romer, D., Weil, D. N. (1992). A Contribution to the Empirics of Economic Growth. – The Quarterly Journal of Economics, 107(2), pp. 407-437. Available at: https://eml.berkeley.edu/~dromer/papers/MRW_QJE1992.pdf [Accessed 14 Jun 2025].

Martincevic, I. (2022). The correlation between digital technology and digital competitiveness. – International Journal for Quality Research, 16(2), pp. 541-558. doi: 10.24874/IJQR16.02-13.

Montgomery, D. C., Peck, E. A., Vining, G.G. (2021). Introduction to Linear Regression Analysis. 6th edn. Hoboken, NJ: Wiley.

National Skills Coalition. (2023). Closing the digital divide: The role of skills in bridging America's workforce equity gap. Available at: https://nationalskillscoalition.org/wp-content/uploads/2023/03/NSC-DigitalDivideSkinny-Report.pdf [Accessed 16 May 2025].

Niranga, M., Sedera, D., Sorwar, G. (2022). Does IT matter (now)? A global panel data analysis of 7 regions from 2018–2020 on digitalization and its impact on economic growth. Presented at the Australasian Conference on Information Systems 2022, Melbourne. SSRN. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4307167 [Accessed 16 May 2025].

Nopianti, R., Ismail, T., Hanifah, I. A., Mulyasari, W. (2025). Model for the Development and Optimization of Growth of Small and Medium-Sized Enterprises (SMEs). – Economic Studies (Ikonomicheski Izsledvania), 34(5), pp. 48-65. Available at: https://archive.econ-studies.iki.bas.bg/2025/2025_05/2025_05_03.pdf [Accessed 27 Aug 2025].

OeAD Digital Skills Office, 2024. Austrian Framework of Reference for Digital Competence (DigComp 2.3 AT). Available at: https://oead.at/en/education-digitisation/digital-skills-office [Accessed 13 Jun 2025].

OECD. (n.d.). Competitiveness and Private Sector Development. Available at: https://www.oecd-ilibrary.org/development/competitiveness-in-south-east-europe_9789264298576-en [Accessed 16 May 2025].

OECD, 2023. Romania – SMART.Edu Strategy (2021-2027). Available at: https://www.oecd.org/education/skills-strategy-romania [Accessed 13 Jun 2025].

Romer, P. M. (1989). Human Capital and Growth: Theory and Evidence. National Bureau of Economic Research Working Paper. Available at: https://www.nber.org/system/files/working_papers/w3173/w3173.pdf [Accessed 14 Jun 2025].

Sagarik, D. (2023). Enhancing digital competitiveness through the lens of digital government among Asian economies. – International Journal of Public Administration in the Digital Age, 10(1). doi: 10.4018/IJPADA.326122.

Salas-Guerra, C. R. (2021). Skills-based on technological knowledge in the digital economy activity. ResearchGate Preprint. Available at: https://www.researchgate.net/publication/348975394_Skills-based_on_technological_knowledge_in_the_digital_economy_activity [Accessed 16 May 2025].

UNITAR. (n.d.). UNITAR Conference on Digital Finance. Available at: https://unitar.org/about/news-stories/news/unitar-conference-digital-finance [Accessed 16 May 2025].

World Economic Forum. (2018). The future of jobs report 2018. Available at: https://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf [Accessed 16 May 2025].

Zareva, I. (2024). Human capital formation in Bulgaria – lessons from the pandemic. – Economic Studies (Ikonomicheski Izsledvania), 33(4), pp. 3-18. Available at: https://archive.econ-studies.iki.bas.bg/2024/2024_04/2024_04_01.pdf [Accessed 27 Aug 2025].