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Digital Transformation and Labour Market Performance in the European Union: Evidence from DESI Indicators

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Abstract

The digital transition is creating new opportunities and challenges for labour markets across the European Union, influencing employment patterns, productivity, labour costs, and working conditions. This study investigates how the four dimensions of the Digital Economy and Society Index (DESI), Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services, are associated with labour market performance in the 27 EU Member States over the period 2017–2022.

The empirical analysis combines DESI and Eurostat data and applies descriptive statistics, panel unit-root tests, Granger causality analysis, and Elastic Net regression modelling. The results suggest that connectivity is the most consistent driver of improved labour market outcomes, being associated with higher labour productivity and fewer long working hours.

The analysis further highlights substantial cross-country variation, indicating that the benefits of digital transformation depend not only on technological progress but also on institutional and economic conditions. These findings provide new evidence on the labour market implications of digitalisation and offer useful insights for policymakers pursuing the objectives of the European Digital Decade.

Keywords: digital transformation, DESI, labour market performance, digital skills, labour productivity, technologies.

1. Introduction

Digitization has radically transformed global economies, reshaping labour markets by introducing new technologies and working patterns. In the European Union, this transition has been accelerated by the need to adapt to the challenges of the 21st century, including globalization, demographic change and recent crises such as the COVID-19 pandemic (Frey & Osborne, 2017). A report by the Organization for Economic Co-operation and Development (OECD, 2019) estimates that around 14% of jobs in developed countries are at risk of automation, while another 32% could undergo significant transformations due to the integration of digital technologies. These shifts raise crucial questions about how the workforce can be prepared to meet the demands of a hyper-connected economy, where digital skills and flexibility are becoming essential.

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In the European context, the economic and social diversity between Member States adds to the complexity of the impact of digitization on employment, productivity and labour costs. Countries with advanced infrastructures and well-developed education systems, such as the Nordic countries, tend to reap the benefits of digitization faster, while Eastern European countries face challenges related to access to technology and vocational training (Acemoglu & Restrepo, 2020; Nicola-Gavrilă et al., 2023). In this respect, understanding regional differences and the factors influencing the labour market becomes essential for the formulation of effective public policies capable of promoting an inclusive digital transition. This study contributes to this debate by providing a rigorous econometric analysis of how the digital transformation is shaping labor force dynamics in the European Union, with implications for economic competitiveness and social cohesion.

Although a growing body of literature examines the relationship between digitalization and labour-market outcomes, empirical evidence remains fragmented regarding the simultaneous effects of digital skills, connectivity, digital technology integration, and digital public services on employment, productivity, labour costs, and working-time patterns across EU Member States (Gaurav et al., 2024; Konle-Seidl, & Danesi, 2022; European Commission, n.d.). Existing studies often focus on individual aspects of digital transformation, while fewer investigations adopt a comprehensive framework based on the Digital Economy and Society Index (DESI) (Zherlitsyn et al., 2025; Buglea et al., 2025, Skare et al., 2023; Bharosa, 2022).

This study contributes to the literature by employing the DESI framework to evaluate how the main dimensions of digital transformation influence labour-market outcomes across EU Member States during 2017–2022. Using Elastic Net regression, the study identifies the relative importance of human capital, connectivity, digital technology integration, and digital public services in explaining variations in productivity, labour costs, and working hours.

2. Literature Review and Theoretical Background

The relationship between technological change and labour market performance has long attracted the attention of economists and policymakers. Beyond the adoption of information and communication technologies (ICT), digital transformation encompasses artificial intelligence (AI), cloud computing, big data analytics, automation, robotics, digital platforms, and advanced connectivity infrastructures that increasingly influence the organization of work and production processes (European Commission, 2024; OECD, 2024). These technologies have altered not only the quantity of employment but also the nature of jobs, skill requirements, productivity dynamics, and labour-market participation patterns.

Previous empirical evidence suggests that digital transformation exerts a significant influence on labour market performance in EU countries. Using DESI indicators, Başol & Yalçın (2020) reported significant relationships between digitalization and several labour market indicators, emphasizing the growing importance of digital readiness for employment and economic performance.

A growing body of literature suggests that technological change does not affect all workers equally. According to the Skill-Biased Technological Change (SBTC) theory, digital technologies tend to increase the demand for highly skilled workers while reducing the relative importance of routine and repetitive tasks (Acemoglu & Restrepo, 2020). Recent evidence indicates that occupations exposed to digital technologies increasingly require advanced cognitive, managerial, analytical, and digital competencies, reinforcing the importance of workforce adaptability and lifelong learning (OECD, 2024; McGuinness et al., 2025). At the same time, concerns remain regarding labour-market polarization, technological displacement, and widening inequalities between workers and regions with different capacities to adopt and benefit from digital innovations (Richiardi et al., 2025).

Within the European Union, digital transformation has become a strategic priority through the Digital Decade agenda, which aims to accelerate digital adoption, improve digital skills, expand connectivity infrastructure, and strengthen digital public services by 2030 (European Commission, 2024). Nevertheless, significant disparities persist among Member States in terms of digital readiness, infrastructure development, workforce skills, and technology integration, suggesting that the labour-market effects of digital transformation may vary substantially across countries (Sofrankova et al., 2025).

Human Capital Theory emphasizes that investments in education, training, and skills development enhance workers' productivity and contribute to economic growth (Becker, 1964). In the context of digital transformation, human capital increasingly includes digital competencies, technological literacy, and the ability to adapt to rapidly changing work environments (Jio & Kero, 2023).

Several empirical studies have documented positive associations between digital competencies and labour productivity, employment opportunities, and earnings, particularly in highly digitalized economies (Acemoglu & Restrepo, 2020; McGuinness et al., 2025). Consequently, countries with stronger digital human capital are expected to experience more favourable labour-market outcomes during the digital transition.

Digital connectivity represents the fundamental infrastructure supporting the functioning of modern digital economies. Broadband networks, high-speed internet access, mobile technologies, and 5G infrastructures enable communication, information exchange, remote work, digital entrepreneurship, and participation in online markets (European Commission, 2024).

The expansion of digital connectivity has generated profound changes in labour-market organization. Improved connectivity facilitates remote and hybrid work arrangements, reduces geographical barriers to employment, and enhances access to education and training opportunities (Bertschek et al., 2013). Furthermore, digital infrastructure contributes to reducing transaction costs, increasing labour mobility, and improving the efficiency of labour-market matching processes between employers and employees (Richiardi et al., 2025).

However, disparities in connectivity continue to contribute to the digital divide, limiting opportunities for individuals and regions with insufficient access to digital infrastructure. As a result, connectivity is increasingly viewed as a prerequisite for inclusive economic development and labour-market participation in the digital age (European Commission, 2024).

The integration of digital technologies within firms constitutes one of the most visible dimensions of digital transformation. Technologies such as artificial intelligence, big data analytics, cloud computing, enterprise software, and e-commerce platforms have significantly altered business models, production systems, and organizational structures (Schilirò, 2024).

The literature generally supports a positive relationship between digital technology adoption and productivity growth. Digital technologies improve information processing, facilitate decision-making, optimize resource allocation, and reduce operational costs. However, empirical evidence also suggests that productivity gains may not occur immediately. Firms often experience adjustment costs associated with technology implementation, employee retraining, organizational restructuring, and process redesign (Acemoglu & Restrepo, 2020; Jiao et al., 2025; Zhou et al., 2025).

This phenomenon is frequently described as the "productivity paradox" of digitalization, whereby substantial investments in technology initially generate limited or even negative productivity effects before long-term benefits materialize. Consequently, the relationship between digital technology integration and labour-market outcomes may be complex and heterogeneous across countries and sectors.

The digitalization of public administration has become an increasingly important component of national digital transformation strategies. Digital public services, commonly referred to as e-government, enable citizens and businesses to access administrative procedures electronically, reducing bureaucratic burdens and improving institutional efficiency (Dunleavy et al., 2006).

Theoretical and empirical studies suggest that digital public services can contribute to economic performance by reducing transaction costs, improving transparency, accelerating administrative procedures, and facilitating interactions between public institutions, businesses, and citizens (European Commission, 2024). In labour markets, digital public services may reduce the time required for regulatory compliance, employment registration, taxation procedures, and access to social services, thereby increasing productive working time and reducing administrative inefficiencies. Moreover, well-developed e-government systems contribute to a more integrated Digital Single Market by enhancing cross-border interoperability and facilitating labour mobility within the European Union (European Commission, 2024).

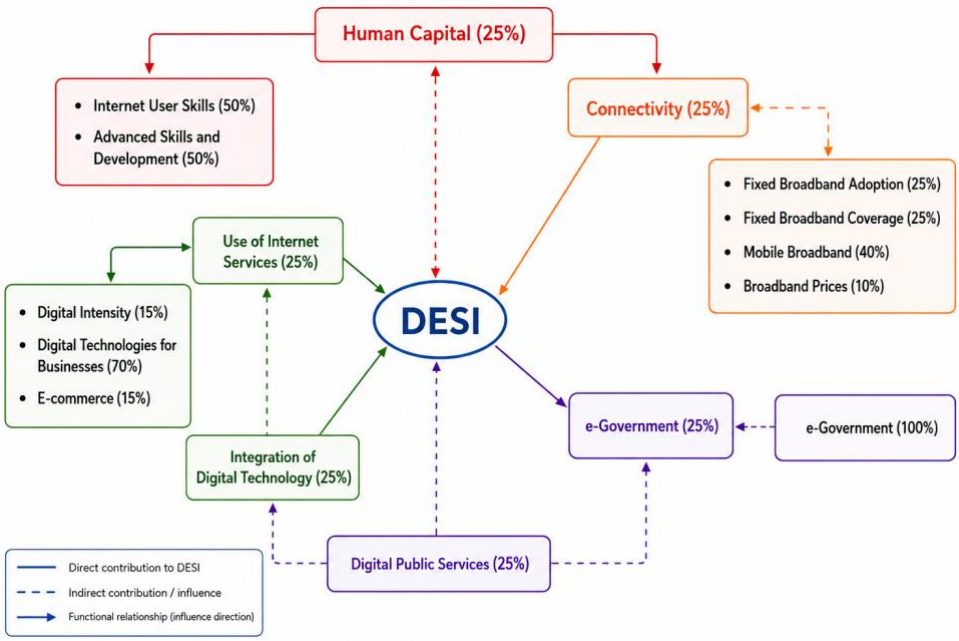
3. Measuring Digital Transformation through the DESI Framework

To evaluate the multidimensional nature of digital transformation across EU Member States, the European Commission developed the Digital Economy and Society Index (DESI). DESI provides a comprehensive framework for assessing national progress in digitalization and monitoring the implementation of the European Digital Decade objectives (European Commission, 2024).

The current DESI framework is structured around four main dimensions: Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services. Together, these dimensions capture both technological and societal aspects of digital readiness, reflecting the capacity of countries to develop digital skills, provide modern digital infrastructure, integrate advanced technologies into economic activities, and deliver efficient digital public services. DESI has also been widely used to investigate patterns of digital convergence across the European Union. For example, Szajt et al. (2024) demonstrated that while EU countries are gradually converging in terms of digital development, significant differences remain across the individual dimensions of digital transformation.

The structure of the Digital Economy and Society Index (DESI), including its main dimensions and sub-dimensions, is presented in Figure 1.

Figure 1. Structure of the Digital Economy and Society Index (DESI)

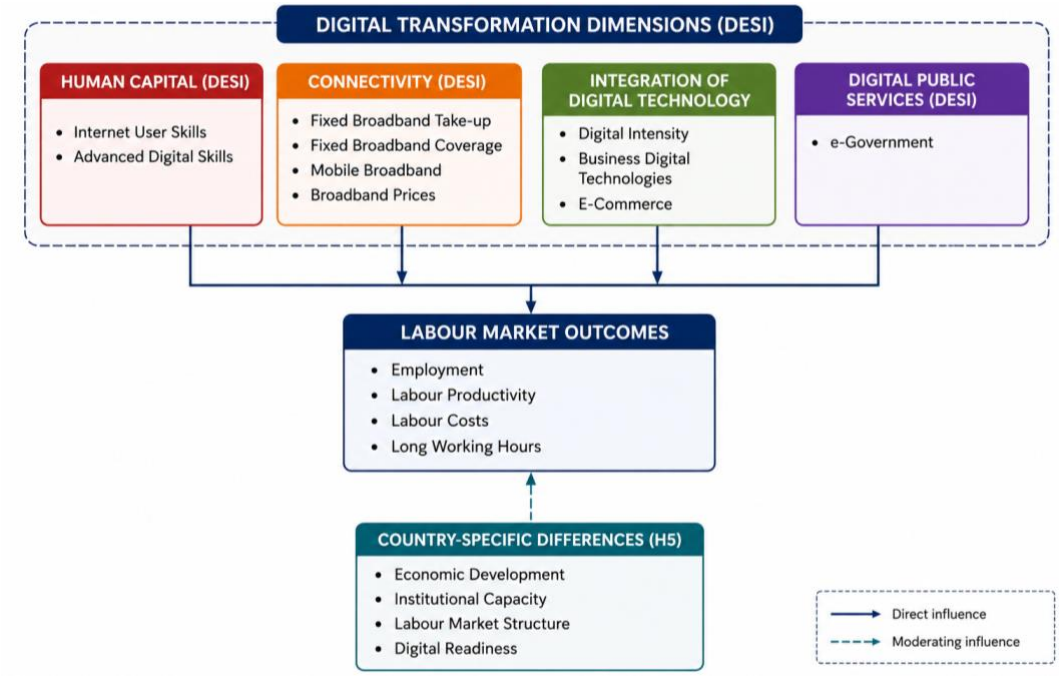


Note: Percentages indicate the weight of each main dimension in the overall DESI index
Source: Authors' elaboration based on the European Commission DESI Methodology (2024).

Because DESI combines indicators relating to individuals, businesses, infrastructure, and public institutions, it offers a comprehensive approach for examining the relationship between digital transformation and labour-market performance across EU Member States.

Despite the increasing use of DESI indicators in policy reports and comparative analyses, relatively limited research has simultaneously examined how these four dimensions influence multiple labour-market outcomes such as productivity, labour costs, and working-time patterns. Maya Matallana et al. (2026), confirms the usefulness of DESI for assessing digital development levels and identifying structural differences among EU economies. DESI provides a robust multidimensional framework for evaluating digital progress and supporting evidence-based policy design.

Figure 2. Conceptual Framework Linking DESI Dimensions and Labour Market Outcomes in EU Member States



Source: Authors' elaboration based on the theoretical framework and hypotheses from the literature review

Figure 2 above illustrates the hypothesized relationships between the four dimensions of digital transformation measured by the Digital Economy and Society Index (DESI) - Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services, and labour market performance indicators. H1–H4 represent the direct effects of each DESI dimension, while H5 acknowledges the possibility that the magnitude of these relationships varies across EU Member States due to differences in economic development, institutional capacity, labour market structure, and digital readiness.

4. Hypotheses Development

Based on the theoretical and empirical literature reviewed above, the following hypotheses are proposed. Human capital represents a critical determinant of labour-market adaptability and productivity in digital economies. Countries with higher levels of digital skills and technological competencies are expected to benefit more effectively from digital transformation processes and to achieve superior labour-market outcomes.

H1: Increasing the level of human capital (basic and advanced digital skills) has a positive impact on employment and labour productivity in EU Member States.

H2: Improved connectivity contributes to reduced long working hours and increased labour productivity.

H3: The integration of digital technologies in enterprises has an ambivalent effect, reducing unit labour costs through automation but potentially generating temporary productivity declines due to adjustment costs.

H4: The development of digital public services (e-government) reduces the time spent on administrative tasks, contributing to a decrease in long working hours and an increase in productivity per hour worked.

H5: The effects of digital transformation on labour-market outcomes may vary across EU Member States due to differences in economic development, institutional capacity, labour-market structure, and digital readiness.

5. Research Methodology

Research Design and Analytical Framework

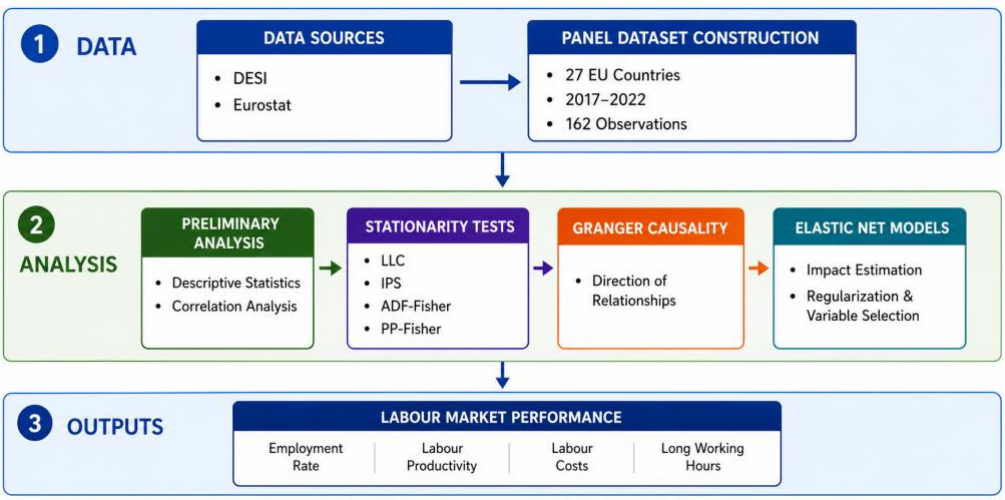
This study investigates the impact of digital transformation on labour market performance across the European Union. Building upon the conceptual framework presented in Figure 2, the empirical analysis examines how the four dimensions of the Digital Economy and Society Index (DESI), Human Capital, Connectivity, Integration of Digital Technology, and Digital Public Services, affect key labour market indicators. The analysis follows a multi-stage empirical strategy that combines descriptive statistics, stationarity testing, causality analysis, and Elastic Net regression modelling. This approach enables the identification of both the direction and magnitude of the relationships between digital transformation and labour market performance while addressing potential multicollinearity among the explanatory variables.

Methodological Steps

The empirical analysis follows a structured research design comprising three main stages: data collection, analytical processing, and output evaluation (Figure 3). First, a balanced panel dataset was constructed using data from the Digital Economy and Society Index (DESI) and Eurostat for the 27 European Union Member States over the period 2017–2022. Second, the analytical stage combined descriptive statistics and correlation analysis with panel unit-root tests to examine the distributional properties and stationarity of the variables.

Subsequently, Granger causality tests were employed to investigate the direction of relationships between the dimensions of digital transformation and labour market indicators, while Elastic Net regression models were estimated to assess the magnitude of these relationships and identify the most influential determinants. Finally, the empirical results were evaluated through four labour market performance indicators: employment rate, labour productivity, labour costs, and long working hours.

Figure 3. Empirical Research Design and Analytical Workflow



Source: Authors' elaboration.

Data and Variables

The empirical analysis uses a balanced panel dataset covering the 27 European Union Member States during the period 2017–2022. The dataset consists of 162 observations (27 countries × 6 years). Data on digital transformation were obtained from the Digital Economy and Society Index (DESI) published by the European Commission, while labour market indicators were collected from Eurostat.

To quantify the impact of digital transformation on labour market performance, Elastic Net (ENET) regression models were estimated. Elastic Net combines the advantages of Ridge regression and Least Absolute Shrinkage and Selection Operator (LASSO), simultaneously addressing multicollinearity and performing variable selection. This characteristic makes ENET particularly suitable for studies involving highly correlated explanatory variables, such as the DESI dimensions.

The Elastic Net estimator minimizes the following objective function:

$$\min_{\beta}\{\Sigma_{(i=1\rightarrow n)}\,(y_i - X_i\beta)^2 + \lambda\,[\,\alpha\,\Sigma_{(j=1\rightarrow p)}|\beta_j| + (1-\alpha)\,\Sigma_{(j=1\rightarrow p)}\beta_j^2]\}$$

where: β = vector of regression coefficients; λ = regularization parameter controlling the degree of penalization; α = mixing parameter that determines the balance between LASSO (L1) and Ridge (L2) penalties; $\Sigma_{(j=1\rightarrow p)}|\beta_j|$ = LASSO penalty (L1 norm) component; $\Sigma_{(j=1\rightarrow p)}\beta_j^2$ = Ridge penalty (L2 norm) component; n = number of observations; p = number of explanatory variables.

Following common practice, $\alpha = 0.5$ was selected, providing an equal balance between coefficient shrinkage and variable selection. The optimal value of λ was determined through five-fold cross-validation using the Mean Squared Error (MSE) criterion.

The statistical analysis of the dimensions of digital transformation, Human Capital, Connectivity, Digital Technology Integration and Digital Public Services, presented in Table 1 provides a relevant overview of the current state of these areas, which are essential for digital progress.

Table 1. Descriptive Statistics of Digital Transformation

Statistic	Human Capital	Connectivity	Integrating digital technology	Digital public services
Mean	11.41167	9.403883	7.374540	14.32554
Median	11.06852	8.936715	7.167009	14.61359
Maximum	17.84766	19.27232	14.77164	22.79479
Minimum	6.869039	3.167988	2.529783	1.853090
Std. Dev.	2.354427	3.205438	2.601790	4.185998
Skewness	0.357277	0.653414	0.416285	-0.472549
Kurtosis	2.664996	3.103606	2.976242	3.136695
Jarque-Bera	4.203994	11.60009	4.682720	6.155286
Probability	0.122212	0.003027	0.096197	0.046068
Sum	1848.690	1523.429	1194.675	2320.737
Sum Sq. Dev.	892.4754	1654.248	1089.859	2821.135
Comments	162	162	162	162

Source: Authors' calculations in EViews based on DESI data obtained from the European Commission.

Table 1 reveals substantial disparities in digital transformation across EU Member States. Among the DESI dimensions, Digital Public Services and Connectivity display the highest average scores, reflecting the significant progress achieved in digital infrastructure and e-government initiatives. In

contrast, human capital shows greater variability across countries, suggesting persistent differences in digital skills and workforce preparedness. The wide ranges observed for all dimensions indicate that the digital transition remains uneven across the European Union, supporting the relevance of investigating cross-country heterogeneity.

Dependent and Independent Variables

The four DESI dimensions constitute the explanatory variables of the analysis:1. Human Capital (HC); 2 Connectivity (CON); 3. Integration of Digital Technology (IDT); 4. Digital Public Services (DPS). To evaluate the effects of digital transformation on labour market outcomes, eight indicators were selected from the Eurostat database. As shown in Table 2, these variables cover employment conditions, working time patterns, productivity, and labour cost dynamics across EU Member States.

Table 2. Indicators of Labour Market Characteristics

Indicator	Acronym	Unit of measurement
Unemployment rate	UNEMP	% of total population
Employment rate	EMP	% of total population
Average number of hours worked per week in main job	HOURS	Number of hours
Working long hours in your main workplace	LONG_HOURS	% of total hours worked
Real labour productivity per person	PROD_PERSON	Index, 2015=100
Real labour productivity per hour worked	PROD_HOUR	Index, 2015=100
Nominal labour cost per person	COST_PERSON	Index, 2015=100
Nominal labour cost per hour worked	COST_HOUR	Index, 2015=100

Source: Authors' compilation in EViews based on Eurostat database metadata.

The descriptive statistics presented in Table 3 indicate considerable variation in labour market performance across EU Member States. Productivity and labour cost indicators exhibit substantial dispersion, reflecting structural differences in economic development and sectoral composition. Similarly, the variation observed in long working hours and employment rates suggests heterogeneous labour market conditions, which may influence the way digital transformation affects economic performance across countries.

Table 3. Descriptive Statistics of labour Market Indicators

Statistic	UNEMP	EMP	HOURS	LONG_ HOURS	PROD_ PERSON	PROD_ HOUR	COST_ PERSON	COST_ HOUR
Mean	5.1037	74.0203	38.1611	6.88	105.33	107.44	113.43	113.09
Median	4.7000	75.3000	38.8000	7.15	103.42	105.13	109.85	110.15
Maximum	16.000	82.9000	42.0000	18.20	134.77	136.72	160.87	163.15
Minimum	1.6000	57.4000	30.6000	0.70	88.22	93.80	89.81	87.97
Std. Dev.	2.4946	5.5140	2.2736	3.63	7.57	7.95	13.12	13.30
Skewness	1.8617	-0.8927	-1.2387	0.27	1.20	1.23	1.18	1.19
Kurtosis	7.2400	3.2610	4.8309	2.92	5.01	4.38	4.47	4.60
Jarque-Bera	214.934	21.9794	64.062	2.13	66.70	54.29	52.67	55.87
Probability	0.0000	0.000017	0.0000	0.34	0.00	0.00	0.00	0.00
Sum	826.800	11,991.300	6,182.10	1,115.30	17,064.77	17,406.0	18,375.8	18,321.04
Sum Sq. Dev.	1,001.958	4,895.083	832.265	2,131.51	9,248.27	10,190.8	27,755.7	28,484.13
Comments	162	162	162	162	162	162	162	162

Source: Authors' calculations based on Eurostat data.

Stationarity Testing

Prior to estimating the econometric models, panel unit-root tests were conducted to determine whether the variables were stationary. Testing stationarity is a fundamental step in panel-data analysis because non-stationary variables may generate spurious relationships, leading to biased estimations and misleading inferences. A stationary series is characterized by a constant mean, variance, and covariance structure over time, ensuring the validity of subsequent econometric procedures.

To assess stationarity, four complementary panel unit-root tests were employed: the Levin-Lin-Chu (LLC) test, the Im-Pesaran-Shin (IPS) test, the ADF-Fisher test, and the PP-Fisher test. These tests were selected because they differ in their assumptions regarding cross-sectional heterogeneity and therefore provide a more robust assessment of the stochastic properties of the data. The LLC test assumes a common unit-root process across cross-sectional units, whereas the IPS test allows for heterogeneous autoregressive coefficients. The ADF-Fisher and PP-Fisher tests combine individual unit-root test statistics across countries and are less restrictive regarding parameter homogeneity.

Granger Causality Analysis

To examine the direction of relationships between digital transformation and labour market performance, pairwise Granger causality tests were conducted. Although Granger causality does not imply true causation, it identifies predictive temporal relationships between variables. The test evaluates whether past values of one variable contain statistically significant information for predicting another variable beyond the information already contained in its own past values (Granger, 1969).

$$y_t = \alpha_0 + \alpha_1 y_{t-1} + \cdots + \alpha_l y_{t-l} + \beta_1 x_{t-1} + \cdots + \beta_l x_{-l} + \epsilon_t \quad (1)$$

$$x_t = \alpha_0 + \alpha_1 x_{t-1} + \cdots + \alpha_l x_{t-l} + \beta_1 y_{t-1} + \cdots + \beta_l y_{-l} + \epsilon_t \quad (2)$$

for all possible pairs of (*x*,*y*) series in the group. The reported F-statistics are the Wald statistics for the joint hypothesis:

$$\beta_1 = \beta_2 = \cdots = \beta_l = 0 \quad (3)$$

This hypothesis tests whether the coefficients on the prior values of the variable that could cause are zero. Rejection of the null hypothesis, "x does not cause Granger y", is realized when the probability value is less than 0.05.

The Granger causality tests reveal only limited evidence of predictive relationships between DESI dimensions and labour market indicators. While some significant causal links are identified, most relationships appear weak or statistically insignificant. These findings suggest that digital transformation influences labour-market outcomes through complex and indirect mechanisms, which justifies the use of Elastic Net regression to capture the magnitude and relative importance of the observed associations.

6. Research Results

6.1. Effect of Digitization on Working Hours

In estimating the impact of digitization on hours worked, we used two indicators as dependent variables: average weekly hours worked (HOURS) and the incidence of long working hours (LONG_HOURS)

The results for the dependent variable HOURS provide valuable insights into the relationship between various determinants and working time (Table 4). The estimated coefficients show that human capital has a significant negative impact on hours worked (-0.412847 for the minimum lambda), suggesting that an increase in education and skill levels may lead to a reduction in the number of hours worked per week. This result is consistent with research suggesting that workers with higher levels of education and skill levels tend to obtain higher paying jobs that often do not require long hours of work to provide a satisfactory income.

Table 4. Impact of Digitization on Average Weekly Working Hours

Dependent Variable: HOURS			
Method: Elastic Net Regularization			
Sample: 2017 - 2022			
Included observations: 162			
Penalty type: Elastic Net (alpha = 0.5)			
Lambda at minimum error: 0.2702			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng= kn, seed=1945803578			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	0.2702	3.035	4.833
Variable	Coefficients		
Human capital	-0.412847	-0.111978	-0.011849
Connectivity	-0.032218	0.000000	0.000000
Integrating digital technologies	-0.155647	-0.066410	-0.002011
Digital public services	0.000000	-0.092239	-0.106594
C	44.32318	41.25008	39.83817
d.f.	3	3	3
L1 Norm	44.92389	41.52071	39.95863
R-squared	0.403673	0.286284	0.167195

Source: Authors' calculations using EViews based on DESI and Eurostat data.

The results indicate that the dimensions of digital transformation exert heterogeneous effects on average weekly working hours. Human capital and the integration of digital technologies display the strongest negative associations, suggesting that digital skills and technology adoption may enhance efficiency and reduce working-time requirements. Connectivity and digital public services show comparatively weaker effects, implying that infrastructure and e-government development alone are insufficient to significantly alter working-time patterns. These findings are broadly consistent with the argument that productivity gains associated with digitalization are primarily realized through organizational adaptation and workforce capabilities rather than through technological infrastructure alone. The Elastic Net model exhibits moderate explanatory power, accounting for approximately 40% of the variation in average weekly working hours.

Table 5. Impact of Digitization on Overtime

Dependent Variable: LONG_HOURS			
Method: Elastic Net Regularization			
Sample: 2017 – 2022	Included observations 162		
Lambda at minimum error: 0.002297			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng= kn, seed=26390168			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	0.002297	1.547	2.463

Variable	Coefficients		
Human capital	0.106550	0.000000	0.000000
Connectivity	-0.452968	-0.298810	-0.221396
Integrating digital technologies	0.836181	0.342161	0.129682
Digital public services	-0.422449	-0.164641	-0.076146
C	9.813679	9.529841	9.101039
d.f.	4	3	3
L1 Norm	11.63183	10.33545	9.528263
R-squared	0.278005	0.204348	0.135386

Source: Authors' calculations using EViews based on DESI and Eurostat data.

The results from Table 5 indicate that digital transformation exerts heterogeneous effects on overtime work. Connectivity and digital public services are associated with fewer long working hours, suggesting efficiency gains and reduced administrative burdens. By contrast, the integration of digital technologies shows a positive association with overtime, indicating that increased digital intensity may extend working time despite productivity improvements. Human capital plays a comparatively limited role. Overall, the model highlights the dual nature of digitalization, which can simultaneously improve efficiency and increase work intensity.

6.2. The Impact of Digitization on Labour Productivity

The Elastic Net estimates reveal heterogeneous effects of the dimensions of digital transformation on labour productivity indicators. Connectivity and digital public services display negative associations with long working hours, suggesting that digital infrastructure and e-government solutions may improve efficiency and reduce the need for overtime. In contrast, the integration of digital technologies exhibits the strongest positive association, indicating that the adoption of advanced digital tools may increase work intensity and extend working time despite potential productivity gains. Human capital shows only a limited contribution to explaining overtime patterns. Overall, the results highlight the dual nature of digital transformation: while some dimensions facilitate more efficient work organization, others may contribute to greater work intensity and blurred boundaries between professional and personal life. The model explains approximately 28% of the variation in long working hours, indicating that additional institutional, sectoral, and organizational factors also influence overtime behaviour.

Table 6. Impact of Digitization on Labour Productivity per Person

Dependent Variable: PROD_PERSON			
Method: Elastic Net Regularization			
Sample: 2017 2022			
Included observations: 162			
Penalty type: Elastic Net (alpha = 0.5)			
Lambda at minimum error: 1.167			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng= kn, seed=1278069159			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	1.167	5.674	5.674

Variable	Coefficients		
Human capital	-0.390913	-0.079998	-0.079998
Connectivity	0.636405	0.146846	0.146846
Integrating digital technologies	-0.453237	-0.001819	-0.001819
Digital public services	0.035065	0.000000	0.000000
C	106.6545	104.8835	104.8835
d.f.	4	3	3
L1 Norm	108.1701	105.1122	105.1122
R-squared	0.114970	0.028793	0.028793

Source: Authors' calculations using EViews based on DESI and Eurostat data.

The results suggest that connectivity is the only dimension consistently associated with higher labour productivity, while human capital and digital technology integration display negative coefficients that may reflect adjustment costs, implementation challenges, and skill mismatches. Digital public services exhibit only a marginal contribution. Overall, the model explains a limited share of productivity variation, indicating that additional institutional and sectoral factors remain important determinants of productivity performance. Taken together, the results for HOURS and LONG_HOURS suggest that digital transformation affects not only the quantity of work performed but also the way working time is organized, with potentially important implications for labour productivity.

Table 7 presents the Elastic Net estimates for real labour productivity per hour worked. The results indicate heterogeneous effects of the different dimensions of digital transformation. Connectivity emerges as the strongest positive determinant of hourly productivity, supporting the view that digital infrastructure facilitates more efficient use of working time and improves organizational performance. In contrast, human capital and the integration of digital technologies display negative associations with productivity, suggesting that the benefits of digital skills and technology adoption may be delayed by adjustment costs, learning processes, and skill mismatches. Digital public services exhibit a moderate positive effect, indicating that improvements in e-government and administrative efficiency can indirectly support productive activities. Overall, the findings are consistent with the literature on the digital productivity paradox, according to which investments in digital technologies do not always translate into immediate productivity gains. The relatively low explanatory power of the model suggests that productivity per hour worked is also influenced by additional organizational, institutional, and sectoral factors beyond the dimensions captured by the DESI framework.

Table 7. Impact of Digitization on Hourly Labour Productivity

Dependent Variable: PROD_HOUR			
Method: Elastic Net Regularization			
Sample: 2017 - 2022			
Included observations: 162			
Penalty type: Elastic Net (alpha = 0.5)			
Lambda at minimum error: 0.6139			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng= kn, seed=217758289			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	0.6139	13.23	13.23

Variable	Coefficients		
Human capital	-0.927570	0.000000	0.000000
Connectivity	0.774356	7.08E-10	7.08E-10
Integrating digital technologies	-0.585571	0.000000	0.000000
Digital public services	0.448051	0.000000	0.000000
C	108.6477	107.4448	107.4448
d.f.	4	1	1
L1 Norm	111.3833	107.4448	107.4448
R-squared	0.183904	1.49E-10	1.49E-10

Source: Authors' calculations using EViews based on DESI and Eurostat data.

However, the low value of the R-squared coefficient (0.183904) indicates that only a small part of the variation in productivity per hour worked is explained by these factors, suggesting that there are other determinants that significantly influence productivity per hour, possibly related to organizational or sectoral factors, as suggested by other studies (O'Mahony & Timmer, 2009).

6.3. The Impact of Digitization on Labour Costs

The Elastic Net results reveal that digital transformation affects labour costs through multiple and sometimes opposing mechanisms. Human capital and the integration of digital technologies exhibit negative associations with labour costs per person, suggesting that efficiency gains and improved resource utilization may outweigh implementation costs over time. Conversely, connectivity and digital public services are positively associated with labour costs, reflecting the investments required to develop digital infrastructure, modernize administrative systems, and attract workers with advanced digital competencies. These findings support the view that digitalization does not uniformly reduce labour costs; rather, its effects depend on the balance between productivity improvements and the additional resources needed to support technological and organizational change. Among the estimated models,

Table 8 displays one of the highest explanatory powers, indicating that labour costs are particularly sensitive to differences in digital transformation across EU Member States.

Table 8. Impact of Digitization on Labour Cost per Person

Dependent Variable: COST_PERSON			
Method: Elastic Net Regularization			
Sample: 2017 - 2022			
Included observations: 162			
Penalty type: Elastic Net (alpha = 0.5)			
Lambda at minimum error: 0.2035			
Regressor transformation: None			
Cross-validation method: K-Fold (number of folds = 5), rng = kn, seed=2013719956			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	0.2035	3.64	7.663
Variable	Coefficients		
Human capital	-2.966814	-1.456987	-0.817205
Connectivity	2.171734	1.633515	1.108945
Integrating digital technologies	-1.643755	-0.821402	-0.348397

Digital public services	1.150597	0.247550	0.000000
C	122.5034	117.2072	114.8974
d.f.	4	4	3
L1 Norm	130.4363	121.3667	117.1719
R-squared	0.457936	0.368571	0.256728

Source: Authors' calculations using EViews based on DESI and Eurostat data.

However, the coefficient of determination (R-squared) of 0.457936 indicates that almost 46% of the variation in unit labor cost per person is explained by the included variables, suggesting a relatively strong relationship between these digital factors and labor costs. Compared to other models analyzed, this model has one of the highest R-squared values, indicating a significant relationship between digitization and labor costs.

These results are consistent with previous studies exploring the impact of digitization on labor costs and productivity. For example, studies by Cardona et al. (2013) and Dong & McIntyre (2014) have shown that while digitization may reduce costs through efficiency, in some sectors and in the short run, wage costs may increase due to increased demand for skilled labor. While Table 8 focuses on labour costs per employee, the next model examines labour costs per hour worked, providing additional insights into how digital transformation influences labour cost efficiency.

Table 9 presents the Elastic Net estimates for nominal labour cost per hour worked. The results broadly confirm the patterns observed for labour cost per person, suggesting that digital transformation influences labour costs through multiple and sometimes opposing channels. Human capital and the integration of digital technologies display negative associations with hourly labour costs, indicating that productivity improvements, process optimization, and more efficient resource allocation may offset part of the costs associated with workforce development and technology adoption. In contrast, connectivity and digital public services exhibit positive associations with labour costs, reflecting the investments required to expand digital infrastructure, modernize administrative systems, and meet the growing demand for digital competencies.

The model explains approximately 44% of the variation in hourly labour costs, indicating a substantial contribution of digital transformation factors to labour cost dynamics across EU Member States. Taken together, the COST_PERSON and COST_HOUR models suggest that digitalization does not uniformly reduce labour costs. While human capital development and technology integration may generate efficiency gains that lower costs over time, investments in connectivity and digital public services often require additional financial resources during the transition period. These findings highlight the multidimensional nature of digital transformation and support the need for policies that simultaneously promote digital infrastructure, workforce development, and organizational adaptation.

Table 9. Impact of Digitization on Hourly Labour Cost

Dependent Variable: COST_HOUR			
Method: Elastic Net Regularization			
Sample: 2017 - 2022			Included observations: 162
Penalty type: Elastic Net (alpha = 0.5)			
Lambda at minimum error: 0.0446			Regressor transformation: None
Cross-validation method: K-Fold (number of folds = 5), rng= kn, seed=615025616			
Selection measure: Mean Squared Error			
	(minimum)	(+ 1 SE)	(+ 2 SE)
Lambda	0.0446	2.436	4.673

Variable	Coefficients		
HUMAN_CAPITAL	-2.941386	-1.737780	-1.173734
CONNECTIVITY	2.213869	1.814361	1.489248
INTEGR_OF_DIGITAL_TECHNOLOGIES	-1.784617	-1.108810	-0.682591
DIGITAL_PUBLIC_SERVICES	1.144453	0.400546	0.062961
C	122.6058	118.3007	116.6142
d.f.	4	4	4
L1 Norm	130.6902	123.3622	120.0228
R-squared	0.437910	0.388995	0.321113

Source: Authors' calculations using EViews based on DESI and Eurostat data.

Analyzing the COST_PERSON and COST_HOUR models, a complex picture of influences on labor costs emerges, highlighting the significant role of human capital and digital technologies. Both models suggest an inverse correlation between human capital and costs, indicating that better-trained employees contribute to economic efficiency, thereby reducing costs per person and per hour. The results also suggest that investing in connectivity and integrating digital technologies may initially generate higher costs, but these expenditures may translate into savings in the long run due to efficiency improvements.

The positive coefficient associated with digital public services in both models indicates that, although the transition to digitization may entail initial costs, in the long run it could lead to increased efficiency in human resource management and better use of the workforce. This finding is in line with the existing literature, which emphasizes the importance of investment in human capital and digitization of processes as a driver of economic growth and competitiveness. The results therefore suggest the need for policy makers to continue to invest in education, training and digital technology to support not only increased economic efficiency, but also to meet the challenges of an increasingly digitalized economy.

7. Discussion

The findings of this study provide new evidence on the complex relationship between digital transformation and labour market performance across European Union Member States. By employing the Digital Economy and Society Index (DESI) as a multidimensional measure of digital transformation and Elastic Net regression as the primary analytical tool, the analysis reveals that the effects of digitalization are neither uniform nor exclusively positive. Instead, the results highlight the coexistence of opportunities and adjustment challenges associated with the digital transition.

One of the most consistent findings concerns the positive role of connectivity in improving labour market outcomes. Across several model specifications, connectivity was positively associated with labour productivity while contributing to a reduction in long working hours. These results support previous evidence suggesting that high-quality digital infrastructure facilitates information exchange, remote work, organizational flexibility, and access to digital services (Bertschek et al., 2013; European Commission, 2024). Enhanced connectivity reduces transaction costs, improves communication efficiency, and enables firms to reorganize production processes more effectively. The findings are also consistent with the objectives of the European Digital Decade strategy, which identifies universal high-speed broadband and 5G coverage as essential prerequisites for economic competitiveness and social inclusion (European Commission, 2024). The positive productivity effects identified in this study suggest that investments in digital infrastructure continue to generate significant economic returns across the European Union.

A second important result concerns the unexpected negative relationship between human capital and labour productivity observed in several regression models. At first glance, this finding appears to contradict Human Capital Theory, which predicts that investments in education and skills should enhance productivity and economic performance (Becker, 1964). However, recent literature suggests that the relationship between skills and productivity is becoming increasingly complex in digitally transforming economies. A possible explanation lies in the existence of skill mismatches, where educational attainment and digital competencies do not fully correspond to labour market requirements (OECD, 2024). In such situations, investments in human capital may not immediately translate into productivity gains because firms and workers require time to adapt to new technologies and organizational practices.

Although digital skills are generally associated with stronger digital transformation performance (Sofrankova et al., 2025), their contribution to labour productivity may depend on the extent to which acquired competencies correspond to labour market needs and firms' technological requirements. Furthermore, highly educated workers may initially be concentrated in sectors undergoing intensive technological restructuring, where short-term adjustment costs temporarily outweigh productivity benefits. Similar observations have been reported in recent OECD analyses emphasizing the importance of aligning digital skills development with labour market demand and lifelong learning policies.

The results also provide evidence supporting the existence of a digital productivity paradox. Although the integration of digital technologies is generally expected to increase efficiency and productivity, the estimated coefficients indicate that technology adoption may temporarily reduce labour productivity while simultaneously lowering labour costs. This finding aligns with the literature on the productivity paradox originally identified by Brynjolfsson & Hitt (2003), which argues that substantial investments in digital technologies often generate delayed productivity gains. Organizations adopting advanced technologies frequently face transition costs related to employee training, organizational restructuring, process redesign, and technological adaptation. Consequently, productivity improvements may only become visible after firms successfully integrate these technologies into their operational routines. The negative productivity coefficients observed in this study therefore should not necessarily be interpreted as evidence of technological failure but rather as indicators of transitional adjustment processes occurring within European labour markets.

The analysis further demonstrates that digital public services exert a more moderate but generally favourable influence on labour market performance. Although the direct effects on productivity are relatively limited, digital public services contribute to reducing administrative burdens and long working hours. These findings support previous research on e-government and digital governance, which emphasizes that digital public administration improves institutional efficiency, reduces bureaucratic costs, and facilitates interactions between citizens, businesses, and public authorities (Dunleavy et al., 2006). The results suggest that the benefits of digital public services are primarily indirect, operating through improvements in institutional quality and administrative efficiency rather than through immediate productivity gains.

Taken together, the findings highlight the importance of considering digital transformation as a multidimensional process rather than a purely technological phenomenon. The positive effects of connectivity coexist with the more ambiguous impacts of human capital and technology integration, indicating that digital transformation requires complementary investments in education, organizational adaptation, and institutional capacity. The results therefore reinforce recent OECD (2024) and European Commission (2024) conclusions that successful digital transitions depend not only on technological infrastructure but also on the ability of individuals, firms, and institutions to adapt to changing economic conditions.

The study also provides empirical support for the existence of cross-country heterogeneity within the European Union. Although all Member States are pursuing digitalization objectives under the Digital Decade framework, the magnitude and direction of the observed relationships differ across countries. Variations in economic development, labour market structures, institutional quality, and digital readiness likely influence how digital transformation affects employment, productivity, and labour costs. These differences help explain why identical digital policies may generate unequal outcomes across national contexts and underscore the need for tailored policy approaches that account for country-specific characteristics.

From a policy perspective, the results suggest several important implications. First, continued investment in digital infrastructure remains essential for improving productivity and supporting labour market efficiency. Second, digital skills policies should focus not only on expanding educational attainment but also on improving the alignment between workforce competencies and labour market needs. Third, organizations adopting advanced digital technologies should accompany technological investments with employee training and organizational transformation strategies in order to minimize short-term productivity losses. Finally, governments should continue expanding digital public services as part of broader efforts to enhance institutional efficiency and support the development of an integrated European digital economy.

Overall, the findings indicate that digital transformation represents both an opportunity and a challenge for European labour markets. While connectivity and digital infrastructure generate clear productivity benefits, the successful realization of the broader economic gains associated with digitalization depends on the ability of firms, workers, and institutions to adapt to an increasingly technology-driven environment. Future research should continue to explore these dynamics using longer time horizons and more disaggregated sectoral data to better capture the evolving relationship between digital transformation and labour market performance.

8. Conclusion

The analysis of the impact of the four dimensions of the digital transformation on the labor market highlighted the central role of human capital in determining employment rates, productivity and labor costs. The results suggest that investments in education and training are essential to improve these indicators. This underlines the need for policy makers to prioritize strategies that develop the skills of the workforce, facilitating adaptation to the demands of a digitized economy. The models showed that connectivity infrastructure significantly influences labor costs and productivity. Positive connectivity coefficients suggest that investments in digital infrastructure can lead to long-term savings and operational efficiency.

The econometric analysis of the impact of the digital transformation on the labor market in the EU Member States partially confirms the hypotheses formulated. H1, which assumed that investment in digital skills increases employment, is partially refuted, as human capital had a negative impact on productivity, possibly due to a mismatch between skills and market requirements ((Santiago et al., 2008). H2, on the positive effect of digital infrastructure on productivity, is supported, with connectivity having a significant positive coefficient, in line with the literature (Bertschek et al, 2013). H3, predicting an ambivalent effect of digital technologies, is supported, with their integration reducing costs but temporarily affecting productivity due to adaptation costs (Brynjolfsson & Hitt, 2003). H4, on the reduction of non-productive time by digitizing public services, is partially supported, with a moderate positive effect on hourly productivity but insignificant for other variables. H5, on differences between Member States, is validated, with results showing significant variations due to heterogeneous levels of digitization (EC, DESI, 2020).

Limitations of the research include the time period under study (2017-2022), which may not capture the long-term effects of digitization, and the lack of sector-specific variables that could explain variations in productivity and costs. Also, the ENET model, although robust, has a moderate explanatory power (R-squared between 0.183904 and 0.457936), suggesting the influence of other factors not included.

Further developments may lie in extending the analysis to post-2022 data to assess the recent impact of emerging technologies (e.g. AI, 6G) and the inclusion of contextual variables such as industrial structure or national training policies. Comparative analyses across sectors (e.g. services vs. industry) and qualitative studies on employee perceptions could complement the understanding of the effects of digitalization.

The results suggest that the rapid integration of digital technologies without adequate training of the workforce may have adverse effects on productivity and costs. The negative coefficients associated with the integration of digital technologies in productivity patterns suggest that a balanced approach is needed to maximize the benefits of digitalization. It is essential that organizations implement transition strategies that include staff training and adaptation to new technological conditions.

CRediT Authorship Contribution Statement

Nicola-Gavrilă, L.: Conceptualisation, methodology, visualisation, writing – original draft preparation, supervision.

Vasilas-Pîrvu, R.: Literature review, formal analysis, data curation, validation, writing – review and editing.

Axinte, G.: Methodology, statistical analysis, interpretation of results, writing – review and editing.

Ciurilă (Tapi), C. A.: Investigation, data collection, literature review, editing.

Călin, O. A.: Data curation, visualisation, proofreading, project administration.

All authors have read and agreed to the published version of the manuscript.

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Conflict of Interest Statement

The authors declare no commercial or financial conflicts of interest. Nicola-Gavrilă, L. is EiC of *JETS* and Vasilas-Pîrvu, R. is EiC of *JGSD*. Both authors were excluded from all editorial decisions related to this manuscript, which was handled independently in accordance with the journal's peer-review and editorial procedures.

Data Availability Statement

The data supporting the findings of this study are publicly available from the European Commission's Digital Economy and Society Index (DESI) database and the Eurostat database. The datasets used and analysed during the current study are available from the corresponding author upon reasonable request.

Ethical Approval Statement

Ethical review and approval were not required for this study because the research relied exclusively on publicly available secondary data obtained from the European Commission (DESI) and Eurostat databases. No human participants, personal data, or animal subjects were involved.

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