


Heterogeneous Economic Returns to Digitalization Across EU Economies: Evidence from Sectoral Panel Analysis

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ABSTRACT

Research background: Digital transformation has become a key driver of productivity growth, innovation, and structural change in modern economies. Within the European Union (EU), the adoption of digital technologies is increasingly viewed as an important factor shaping competitiveness and long-term economic performance. However, empirical evidence on how digital intensity translates into sectoral economic outcomes across EU economies remains limited and often overlooks cross-country heterogeneity.

Purpose of the article: The main aim of this paper is to examine the relationship between digital intensity and sectoral value added across EU economies and to determine whether the economic returns to digitalization vary across countries. The study also investigates whether EU economies can be grouped into distinct clusters according to their digital intensity and economic performance.

Methods: The empirical analysis is based on sector-level panel data for selected economic sectors across EU member states covering the years 2022–2024, sourced primarily from Eurostat databases on digital intensity and sectoral economic performance. Digitalization is measured using the Digital Intensity Index (DII), which captures the extent to which enterprises adopt and integrate digital technologies. The relationship between digital intensity and sectoral value added is examined using fixed-effects panel regression models controlling for sector-, country-, and time-specific heterogeneity. A baseline specification estimates the average effect of digital intensity, while a heterogeneous country-slopes model captures potential differences in digital returns across national economies. To explore structural similarities among EU economies, hierarchical cluster analysis using Ward's method and squared Euclidean distance is also applied.

Findings & Value added: The findings offer implications for both policymakers and business practitioners. For policymakers, the results suggest that digitalization strategies should be tailored not only to country-specific conditions but also to sectoral characteristics, as the economic returns to digital technologies differ across industries. For firms and sectoral managers, the findings indicate that investments in digital technologies may yield larger productivity gains, particularly in sectors and countries where digital adoption is still evolving, underscoring the importance of aligning digital strategies with sector-specific operational and technological conditions.

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INTRODUCTION

Digitalization has become a central driver of economic transformation in contemporary economies (Valaskova et al., 2025a). The rapid diffusion of digital technologies—including cloud computing (Wang et al., 2025), data analytics, digital platforms (Chatterjee et al., 2025), and advanced communication infrastructures (Valaskova et al.,

2025b)—has substantially reshaped production processes, business models, and patterns of value creation across industries (Figura et al., 2025). Within the European Union (EU), digital transformation is widely regarded as a key pillar of long-term economic competitiveness (Nagy, 2025), innovation capacity (Zabojnik & Branch, 2025), and productivity growth (Radulescu, 2025). Policy initiatives such as the Digital Europe Programme and the European Digital Strategy emphasize

strengthening digital capabilities across firms and sectors to support sustainable economic growth and enhance the global competitiveness of EU economies (Pentek et al., 2025). In this context, digital intensity—commonly measured as the extent to which enterprises adopt and integrate digital technologies into their operations—has attracted increasing attention as an indicator of economic modernization and structural change.

A growing body of empirical literature reports a positive relationship between digitalization and economic performance. Prior studies show that higher levels of digital adoption are associated with increased productivity, improved firm performance, and higher value added, contributing to stronger macroeconomic growth. Evidence from European economies further suggests that digital technologies can enhance labour productivity, support innovation, and strengthen competitiveness across manufacturing and service sectors. Nevertheless, important gaps remain in the literature. Many studies rely on aggregate indicators of digitalization and economic performance, often overlooking sectoral differences within national economies. Empirical analyses also frequently assume relatively uniform digitalization effects across countries, despite differences in economic development, institutional conditions, and sectoral structures. Moreover, limited attention has been devoted to assessing whether EU countries form distinct digital–economic groupings when digital intensity and economic performance are considered jointly.

These limitations point to a research gap in understanding how digital intensity translates into economic outcomes across sectors and national contexts within the EU. Addressing this gap requires empirical analyses that combine sector-level economic indicators with country-specific digitalization measures and allow for heterogeneity across national economies. In this regard, the present study contributes to the literature by examining both the economic effects of digital intensity and structural differences in digital development across EU countries. Specifically, the paper addresses the following research questions:

RQ1: What is the relationship between digital intensity and sectoral value added in EU economies, and does this relationship vary across countries?

RQ2: Do EU economies form distinct groups according to their digital intensity and economic performance?

To address these questions, the main aim of this paper is to examine the relationship between digital intensity and sectoral economic performance across EU economies, with particular emphasis on cross-country heterogeneity in the economic returns to digitalization. The analysis employs the Digital Intensity Index (DII) as a key indicator capturing the extent to which enterprises adopt and integrate digital technologies into their business activities. Using sector-level panel data for EU member states, the empirical investigation focuses on selected sectors representing both traditional industries and knowledge-intensive services. The relationship between digital intensity and sectoral value added is first estimated using

fixed-effects panel regression models that control for sector-specific, country-specific, and time-specific heterogeneity. In addition to the baseline specification, which estimates the average effect of digital intensity, a heterogeneous country-slopes model is used to capture potential cross-country differences in marginal economic returns to digitalization. The novelty of this study lies in combining sector-level econometric analysis with a country-level clustering approach, enabling assessment of both the productivity effects of digital intensity and broader structural patterns of digital–economic development across EU economies. To further examine these patterns, hierarchical cluster analysis is applied to group countries based on digital intensity, estimated digital returns, and economic performance indicators.

The remainder of the paper is organized as follows. The Theoretical Background section reviews the literature on digital transformation, digital intensity, and their relationship with economic performance. The Research Objective, Methodology and Data section defines the research objective, describes the dataset and variables, and presents the econometric and clustering methods. The Results and Discussion section reports and interprets the empirical findings, including regression estimates and clustering results. Finally, the Conclusion section summarizes the main results, discusses implications for understanding digital transformation in EU economies, and outlines directions for future research.

THEORETICAL BACKGROUND

Higher digital intensity is systematically associated with stronger firm-, sector-, and economy-wide performance in the EU, and this relationship is commonly framed in terms of productivity, value added, and GDP. Digital technologies are also increasingly used to support economic decision-making processes, including financial analysis and risk assessment (Balcerzak et al., 2025a, 2025b). Verdes et al. (2024) show that a higher share of SMEs with at least basic digital intensity is positively correlated with value added per SME across EU countries. Using panel data for the EU-27, Kadarova et al. (2023) find that digital intensity and adoption of digital tools significantly improve small and medium-sized enterprise (SME) performance, emphasizing that more digitalized firms generate higher value added and better growth prospects. Brodny and Tutak (2022a) report that SMEs create 53% of total value added in the EU-27 non-financial business sector and show that countries with more digitally mature SMEs achieve higher GDP per capita, implying that SME-level digitalization scales up to stronger national value creation. In a related study on enterprise digitalization, the same authors construct firm-level digitalization indices and identify a positive, statistically significant association between business digitalization and key macroeconomic indicators (Tutak & Brodny, 2022; Brodny & Tutak, 2022b). Privara et al. (2025) further show that providing portable digital devices to employees in EU-25 countries increases gross value added per unit of net fixed assets, whereas connectivity without

adequate skills may reduce this ratio, highlighting that effective digital intensity—rather than mere technological access—enhances capital productivity.

Additional empirical evidence supports the macroeconomic relevance of digitalization. Rehman and Nunziante (2023) demonstrate that digital-economy proxies such as e-government, e-commerce, and household internet access have a positive and statistically significant impact on regional total factor productivity across EU-27 NUTS2 regions. Olczyk and Kuc-Czarnecka (2022), Bocean and Varzaru (2023), Criveanu (2023), and Lobont et al. (2025) all find that composite measures of digital transformation exert a strong positive effect on GDP per capita and related output indicators. Similar conclusions are reported by Valaskova et al. (2025c), who show that strategic alignment between digital transformation initiatives and organizational processes contributes positively to firms' financial performance. Sector- and firm-level studies point in the same direction. Recent research also emphasizes the growing role of advanced Industry 4.0 technologies, including artificial intelligence, digital twins, and Internet-of-Things-based systems, which enable real-time monitoring and optimization of production processes (Nagy et al., 2025). Lastauskaite and Krusinskas (2023) document that digital investment in manufacturing firms across EU-27 countries is closely associated with higher operating revenues, indicating that digital technologies can enhance productivity and value creation in industrial activities. Da Silva et al. (2025) similarly show that higher digital maturity in manufacturing SMEs is linked to increased labour productivity and export performance. Ivanova and Grmanova (2023), using Digital Economy and Society Index (DESI) dimensions as inputs in data envelopment analysis (DEA) models, find that more advanced digitalization is associated with a higher information and communication technology (ICT) share of GDP. Kyshakevych et al. (2024) further demonstrate that in countries such as Malta and the Netherlands, high SME digital intensity combined with cloud adoption and e-commerce turnover is efficiently translated into higher GDP per capita, exports, and stronger international investment positions.

Across these contributions, digital intensity is operationalized using various indicators, including SME DII measures, DESI components, adoption of cloud and big-data technologies, and broader digital-economy proxies capturing firms' digital capabilities. Within the EU statistical framework, the DII is among the most widely used indicators for assessing enterprise digital adoption, as it aggregates the use of several digital technologies into a single composite measure of digital maturity. Despite differences in data, methodology, and levels of analysis, the empirical literature consistently suggests that higher digital intensity is associated with stronger productivity performance and greater value creation. Overall, EU-focused studies indicate a predominantly positive relationship between digital intensity and economic performance across firm and sectoral levels, providing a strong basis for expecting a similar association at the sectoral level in

EU economies. This evidence provides the theoretical and empirical foundation for the first hypothesis:

H1: Higher digital intensity is positively associated with sectoral value added across EU economies.

A related strand of literature examines heterogeneity in digital transformation across EU countries and the emergence of distinct digital–economic patterns. Bocean and Varzaru (2023) analyse the systemic interaction between digital transformation, sustainability orientation, and economic outcomes. Using factor models and cluster analysis, they identify groups of EU economies characterized by different digital and sustainability profiles and show that digitally advanced clusters achieve the highest economic performance, whereas lagging clusters exhibit lower digital readiness and weaker outcomes. Bahidi and Dobos (2023) examine digital development through the lens of the EU core–periphery divide. Using DESI sub-dimensions together with posets, tiered DEA, and cluster analysis, they identify country groups with similar levels of digital development and show that economically stronger countries are typically concentrated among digital leaders, whereas peripheral economies more frequently appear among digital laggards, although notable exceptions such as Estonia exist.

Other studies explore clustering patterns in broader digital-economy contexts. Bilozubenko et al. (2020) cluster EU economies using a comprehensive set of digital-economy indicators and identify leaders, followers, and outsiders, interpreting these clusters as evidence of persistent digital convergence and divergence within the EU. Pinto et al. (2023) analyze clusters based on three latent dimensions of digitalization, especially digital empowerment, enterprise digitalization and broadband access, and reveal situations where strong digital infrastructure does not necessarily translate into high levels of enterprise digitalization, thereby influencing national competitiveness and innovation capacity. Further contributions focus on the relationship between business-level digitalization and macroeconomic outcomes. Brodny & Tutak (2022a) classify EU-27 countries according to the digital maturity of SMEs and show that clusters characterized by highly digitalized SMEs are generally associated with higher GDP per capita, whereas several newer member states form a distinct lagging cluster. Similarly, Chepeliuk et al. (2025) cluster countries based on business-environment digitalization indicators and the Legatum Prosperity Index, highlighting that institutional quality and welfare conditions influence both digitalization strategies and economic competitiveness. Several studies also analyze digital clustering within the broader context of Industry 4.0 and technological transformation. Malkowska et al. (2021) and Hunady et al. (2022) identify groups of countries with different levels of technological performance within the frameworks of Society 4.0, Economy 4.0, and Companies 4.0, interpreting these patterns as evidence of persistent digitalization gaps between Northern and Southern Europe. Similarly, Stankovic et al. (2021) construct a composite digital competitiveness index and identify clusters of countries characterized by

different levels of digital performance, with Nordic economies consistently appearing among the digital leaders. Recent research further highlights that digital clusters do not always align perfectly with other dimensions of socio-economic development. Kosikova & Vasanicova (2025) classify EU countries separately according to digital readiness and sustainable development performance, identifying cases where digital leaders perform relatively weaker in sustainability outcomes and vice versa. Pakhnenko et al. (2025) identify clusters of European economies using self-organizing maps based on ICT infrastructure, sectoral ICT activity, and digital adoption indicators, revealing a persistent divide between digital leaders and less advanced economies despite gradual convergence trends.

Taking together, these studies demonstrate that digital transformation across EU economies is characterized not only by differences in the intensity of digital adoption but also by distinct structural patterns linking digitalization to economic performance. Empirical studies focusing on EU economies consistently show that digital transformation is unevenly distributed across countries and is associated with distinct patterns of economic performance. Cluster analyses and comparative studies identify groups of countries with similar levels of digital development, often distinguishing between digital leaders, followers and catching-up economies. These findings indicate that differences in digital intensity are closely linked to broader structural and economic characteristics, supporting the expectation that EU economies can be grouped into distinct digital-economic clusters. Consequently, the literature suggests that EU countries may form groups with similar digital-economic profiles, which motivates the second hypothesis:

H2: EU economies can be grouped into distinct clusters reflecting differences in digital intensity and economic performance.

Building on these insights, the empirical analysis in this study examines both the productivity implications of digital intensity and the structural heterogeneity of digital transformation across EU economies. By combining sectoral regression analysis with cluster analysis of national digital-economic characteristics, the study aims to provide a more comprehensive understanding of how digitalization translates into economic outcomes within the EU.

RESEARCH OBJECTIVE, METHODOLOGY AND DATA

The main aim of this paper is to operationalize the research objective by defining the dataset, variables and empirical methods used to examine the relationship between digital intensity and sectoral economic performance across EU economies. The empirical analysis is based on panel data covering selected sectors of EU economies. The data are primarily sourced from Eurostat databases, which provide harmonized and comparable statistics on digital intensity and sectoral economic performance across EU member states. Eurostat data are widely used in empirical economic research due to their

methodological consistency, reliability and cross-country comparability, making them suitable for panel data analysis in the EU context. The dataset combines sector-level indicators of value added and employment with country-level indicators of digital intensity for the years 2022 and 2024. The research sample includes all EU member states and focuses on sectors that are particularly relevant for analyzing the economic impact of digitalization. Specifically, the analysis covers several key sectors defined according to the NACE Rev. 2 classification, including manufacturing (C), construction (F), wholesale and retail trade (G), transportation and storage (H), information and communication (J), professional, scientific and technical activities (M), and administrative and support service activities (N). These sectors represent a broad spectrum of economic activities combining traditional industries with knowledge-intensive service sectors. They were selected because they differ substantially in their level of digital adoption and technological intensity, which provides a suitable setting for examining how digitalization translates into sectoral economic performance. At the same time, these sectors account for a significant share of economic output and employment within EU economies, ensuring sufficient variation in both digitalization and productivity indicators.

The analysis focuses on two time periods, namely 2022 and 2024. The choice of these years is primarily driven by data availability for the DII in its most recent and methodologically consistent specification. These years also capture the latest stage of digital transformation in EU economies, allowing the analysis to reflect current digitalization patterns. However, the relatively short time dimension should be considered when interpreting the results.

The empirical analysis relies on three key variables describing sectoral economic performance and the level of digitalization. Their definitions and measurements are summarized in Table 1. Sectoral value added represents the total economic output generated by a given sector within a country and reflects its contribution to national economic performance. Digital intensity captures the extent to which firms adopt and integrate digital technologies into their business processes, including the use of advanced digital tools, data analytics and digital communication systems.

To provide an overview of the analyzed variables, Table 2 reports descriptive statistics for the variables included in the empirical analysis. The distribution of sectoral value added appears relatively balanced after logarithmic transformation, while the digital intensity index shows greater variability across observations, indicating differences in the level of digital adoption among EU economies. Employment also exhibits variation across sectors and countries, reflecting differences in sectoral labor intensity.

Before estimating the regression models, the relationships among the main variables were examined using correlation analysis. Pearson correlation coefficients

Table 1: Definition and measurement of variables used in the empirical analysis

Variable	Variable code	Measurement and definition	Empirical studies
Sectoral value added	Ln (VA)	Natural logarithm of sectoral value added representing the economic output generated by individual sectors in each country and year. Logarithmic transformation is applied to reduce skewness in the distribution of the variable and to allow the estimated coefficients to be interpreted as elasticities.	Brodny & Tutak (2022a); Olczyk & Kuc-Czarnecka (2022); Rehman & Nunziante (2023)
Employment	Ln (EMP)	Natural logarithm of the number of employees in each sector. The logarithmic transformation accounts for large differences in sector size across countries and ensures that estimated relationships capture proportional rather than absolute changes.	Kadarova et al. (2023); Privara et al. (2025)
Digital intensity	DI	Share of enterprises with a very high DII (Version 4). This composite indicator reflects the adoption of multiple digital technologies and digital business processes by firms. The use of Version 4 ensures methodological consistency with the most recent EU measurement of digitalisation. In this study, digital intensity (DI) is defined as this DII-based indicator and is used as a simplified notation throughout the paper.	Criveanu (2023); Brodny & Tutak (2022b); Verdes et al. (2024); Kyshakevych et al. (2024)

Source: own elaboration

Table 2: Descriptive statistics of the main variables

Variable	Mean	Std. dev.	Q1	Median	Q3	Min	Max
Ln (VA)	9.636	1.516	8.361	9.568	10.783	6.485	13.566
Ln (EMP)	5.549	1.389	4.698	5.499	6.531	2.600	8.921
DI	8.434	10.267	2.248	5.045	10.008	0.000	57.190

Note: Q1 and Q3 denote the first and third quartiles of the variable distribution, respectively. Source: own elaboration

were calculated to assess the strength and direction of pairwise relationships between the variables. In addition to correlation coefficients, multicollinearity diagnostics were conducted using the variance inflation factor (VIF). Testing for multicollinearity is important in regression analysis because highly correlated explanatory variables may distort coefficient estimates and reduce the reliability of statistical inference.

To examine the relationship between digitalization and sectoral economic performance, two panel regression models were estimated. The first specification represents the baseline fixed-effects model, which estimates the average effect of digital intensity on sectoral value added while controlling for sectoral, temporal, and country-specific heterogeneity. The model can be expressed as follows:

$$\ln(VA_{i,s,t}) = \beta_0 + \beta_1 DI_{i,s,t} + \beta_2 \ln(EMP_{i,s,t}) + \gamma_s + \delta_t + \mu_i + \varepsilon_{i,s,t}$$

where $\ln(VA_{i,s,t})$ represents the logarithm of sectoral value added in country i , sector s , and year t , $DI_{i,s,t}$ denotes the level of digital intensity, $\ln(EMP_{i,s,t})$ represents the logarithm of sectoral employment, γ_s captures sector fixed effects, δ_t represents year fixed effects, μ_i denotes country fixed effects, and $\varepsilon_{i,s,t}$ is the error term. This specification controls for unobserved heterogeneity across sectors, countries, and time periods that could influence sectoral economic performance.

To capture potential differences in the economic returns to digitalisation across countries, a second specification introduces country-specific slopes for digital intensity.

This heterogeneous specification allows the effect of digital intensity to vary across national economies through interaction terms between digital intensity and country identifiers. The model takes the following form:

$$\ln(VA_{i,s,t}) = \beta_0 + \beta_1 Country_i \times DI_{i,s,t} + \beta_2 \ln(EMP_{i,s,t}) + \gamma_s + \delta_t + \mu_i + \varepsilon_{i,s,t}$$

This specification makes it possible to estimate country-specific marginal effects of digital intensity and assess whether the productivity gains associated with digitalisation differ across EU economies.

In the final stage of the empirical analysis, a cluster analysis was performed to identify groups of EU economies with similar digital-economic characteristics. The clustering procedure was applied to country-level indicators capturing digital intensity, estimated digital returns from the regression models, and economic performance. Hierarchical cluster analysis was conducted using Ward's linkage method, which minimises the within-cluster variance during the clustering process. The squared Euclidean distance metric was used as the measure of dissimilarity between observations. This approach is widely used in empirical economic studies because it tends to produce compact and well-separated clusters. The clustering results are visualised using a dendrogram, which illustrates the hierarchical structure of similarities among EU economies. Based on the inspection of the dendrogram and the rescaled distance coefficients, the final cluster solution was selected to identify groups of countries with comparable digital-economic profiles

RESULTS AND DISCUSSION

The empirical analysis begins with an examination of the basic statistical relationships among the analyzed variables. Table 3 summarizes the Pearson correlation coefficients among the main variables together with VIF statistics, providing an initial overview of the relationships in the dataset. As expected, sectoral value added and employment exhibit a strong positive correlation, reflecting the relationship between sector size and economic output. In contrast, digital intensity shows only a weak association with value added, suggesting that the economic effects of digitalization may depend on additional structural factors captured in the regression models. The correlation between digital intensity and employment is slightly negative. The VIF values remain close to 1, confirming that multicollinearity is not a concern and that the explanatory variables can be jointly included in the regression models.

Table 3: Modified correlation matrix and multicollinearity diagnostics

	Ln (VA)	Ln (EMP)	DI	VIF
Ln (VA)	1			
Ln (EMP)	0.912*	1		1.025
DI	0.027	-0.156*	1	1.087

* denotes statistical significance at the 1% level.

Source: own elaboration

Table 4 presents the results of the baseline fixed-effects model examining the relationship between digital intensity and sectoral value added across EU countries. The coefficient of digital intensity is positive but statistically insignificant, suggesting that, on average, higher digital intensity is not associated with higher sectoral value added once sector, year, and country fixed effects are controlled for. This finding contrasts with a large part of the existing empirical literature that identifies a positive relationship between digitalisation and economic performance. Rehman & Nunziante (2023) show that digital economy indicators significantly increase regional total factor productivity across EU NUTS-2 regions, while Olczyk & Kuc-Czarnecka (2022) find that higher levels of digital transformation are associated with higher GDP per capita in EU economies. A possible explanation for this difference lies in the stricter econometric specification applied in this study, which simultaneously controls for sectoral, temporal and country-specific heterogeneity and may therefore absorb part of the average digitalisation effect identified in more aggregated analyses.

Table 4: Regression results of baseline model and heterogeneous country-slopes specification

Var.	Estimates of baseline model	Estimates of country slopes
Intercept	6.327** [17.350]	6.653** [18.721]

DI	0.002 [0.679]	-
Ln (EMP)	0.657** [12.559]	0.610** [11.971]
Year 2022	-0.074* [-2.096]	-0.067 [-1.917]
Country × DI	Not included	Included
Sector FE	Included	Included
Country FE	Included	Included
Observations	376	376

Dependent variable: Ln (VA). t statistics in brackets. FE denotes fixed effects. ** and * denote statistical significance at the 1% and 5% levels, respectively.

Source: own elaboration

In contrast, employment exhibits a strong and statistically significant positive association with value added, indicating that sectors with higher labour input tend to generate higher economic output. The joint significance of sector and country fixed effects further confirms substantial structural heterogeneity across EU industries and national economies. The importance of such structural differences has also been emphasised in earlier research, where the productivity effects of digital technologies are shown to depend strongly on complementary factors such as human capital, organisational capabilities and innovation systems (Liang & Zhang, 2024).

Table 4 extends the baseline specification by allowing the effect of digital intensity to vary across countries through country-specific interaction terms. The joint significance test of these interaction effects indicates that the impact of digital intensity differs significantly across EU countries (,), suggesting that the economic returns to digitalisation are not uniform across national economies. This finding is consistent with previous research emphasising the heterogeneous nature of digital transformation across the EU. Bocean & Varzaru (2023) show that EU countries differ considerably in how digital capabilities translate into economic performance, while Banhidi & Dobos (2023) identify persistent digital development gaps between core and peripheral EU economies. Similar conclusions are reported by Valaskova et al. (2025a), who demonstrate that digital transformation outcomes across EU countries are strongly influenced by differences in governance frameworks and institutional capacities.

Table 5 reports the country-specific slope coefficients for digital intensity. Positive and statistically significant digital returns are observed in a limited number of EU economies, namely Bulgaria, Cyprus, Ireland, Malta and Romania, indicating that the economic impact of digital intensity varies considerably across countries. These results suggest that digitalisation may generate stronger marginal productivity gains in certain national contexts even when the average effect across the EU remains statistically insignificant. These cross-country differences in digital returns may be explained by variations in institutional quality, digital infrastructure, human capital and the level of technological readiness across EU economies. In catching-up economies, digital technologies may generate stronger marginal productivity gains as they comple-

ment existing gaps in efficiency and modernization, whereas in more advanced economies, the marginal effects of additional digital investments may be lower due to already high levels of digital saturation.

Table 5: Country-specific effects of digital intensity

Country	Digital intensity coefficient
Bulgaria	0.025*[1.811]
Cyprus	0.025**[3.015]
Ireland	0.035**[4.638]
Malta	0.023**[3.519]
Romania	0.041*[1.911]

Dependent variable: Ln (VA). Only statistically significant country-specific coefficients from the heterogeneous slopes model are reported. *t* statistics in brackets. ** and * denote statistical significance at the 1% and 5% levels, respectively. Source: own elaboration

Interestingly, the countries with significant digital returns do not correspond exclusively to the most digitally advanced economies in the EU. Instead, stronger marginal effects appear in several smaller or catching-up economies. A similar pattern has been identified by Brodny & Tutak (2022a), who classify EU countries according to SME digital maturity and identify a group of newer member states with increasing digital capabilities but distinct structural economic conditions. Bilozubenko et al. (2020) also document clusters of EU economies with different levels of digital development, including catching-up groups where digital transformation may generate relatively strong productivity gains. This interpretation is further supported by broader evidence showing that firm performance and growth dynamics depend on multiple structural and managerial factors, including financial performance conditions and risk management practices (Belas et al., 2025).

A closer inspection of the country-specific coefficients confirms that positive and statistically significant digital returns occur primarily in Bulgaria, Romania, Cyprus, Malta and Ireland. This pattern suggests that the marginal economic benefits of digitalisation may be particularly pronounced in economies where digital technologies are still expanding and becoming integrated into production processes. Conversely, in highly digitalised economies, additional productivity gains from further digital adoption may be more limited due to already high levels of digital saturation. This interpretation is consistent with recent research highlighting that the economic outcomes of digital technologies may vary depending on national institutional arrangements and labour-market structures (Remeikiene et al., 2025).

To further explore these cross-country differences, cluster analysis is applied to identify groups of EU economies with similar digital-economic profiles. While the regression results reveal substantial heterogeneity in country-specific digital returns, cluster analysis enables the identification of broader structural similarities across national

economies. Hierarchical clustering groups countries according to their digital intensity, estimated digital returns and economic performance indicators. The use of clustering techniques in this context is consistent with earlier studies identifying digital leaders, followers and laggards within the EU (Bilozubenko et al., 2020; Brodny & Tutak, 2022a; Stankovic et al., 2021). A comparable methodological approach is also employed by Valaskova et al. (2025b) in analysing disparities in digital transformation within the European public sector.

Figure 1 presents the dendrogram obtained from the hierarchical cluster analysis using Ward's linkage method. The dendrogram illustrates the relative similarity between EU economies based on their digital intensity, estimated digital returns and economic performance indicators. Countries connected at lower rescaled distances exhibit more similar digital-economic profiles, whereas those joined at higher distances are more structurally different. Such clustering approaches are commonly used to analyse digital competitiveness and innovation patterns across countries (Bahidi & Dobos, 2023; Pinto et al., 2023).

Based on the inspection of the dendrogram and the rescaled distance coefficients, a four-cluster solution was selected, providing a clear separation of EU economies with distinct digital-economic characteristics (Table 6). This multi-cluster structure aligns with previous research suggesting that EU countries form several intermediate digital development groups rather than a simple division between digital leaders and laggards (Bilozubenko et al., 2020; Malkowska et al., 2021; Pakhnenko et al., 2025).

Table 6: Cluster classification of EU economies based on digital-economic characteristics

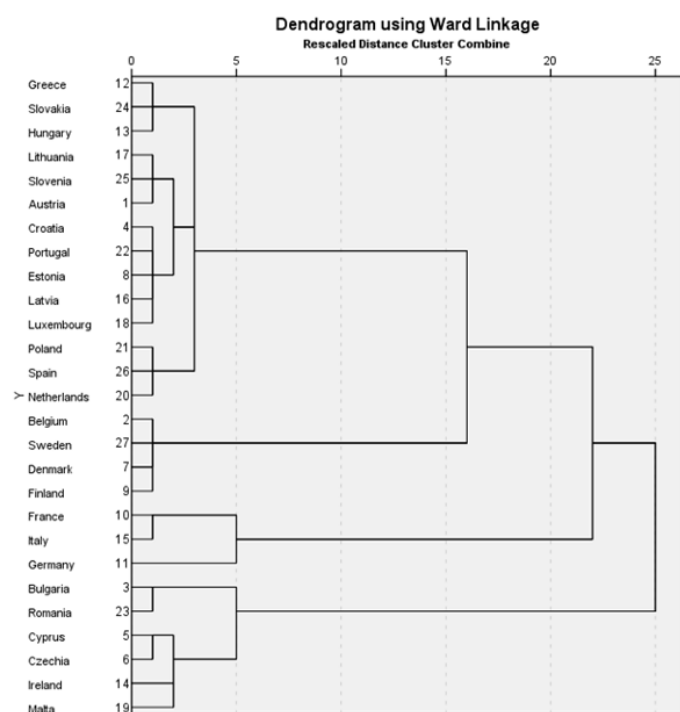
Cl.	Digital-economic profile	Countries
C1	Moderate digital adopters	Austria, Croatia, Estonia, Greece, Hungary, Latvia, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Slovenia, Spain
C2	Digital leaders	Belgium, Denmark, Finland, Sweden
C3	Large advanced economies	France, Germany, Italy
C4	Catching-up digital performers	Bulgaria, Cyprus, Czechia, Ireland, Malta, Romania

Source: own elaboration

The cluster analysis identifies four groups of EU economies with different digital-economic profiles. The first cluster represents a heterogeneous group of moderately digitalized economies, including several Central and Southern European countries. The second cluster consists of digitally advanced Northern European economies characterized by high digital intensity and strong econo-

mic performance. The third cluster includes large Western European economies such as Germany, France and Italy, while the fourth cluster comprises several smaller or catching-up economies where the regression results indicate relatively stronger marginal productivity gains from digitalization. This clustering pattern partly corresponds with earlier empirical findings on the digital divide in Europe. Studies by Stankovic et al. (2021) and Banhidi & Dobos (2023) consistently identify Nordic economies as digital leaders and several Eastern European countries as digital followers or catching-up economies. Similar cross-country heterogeneity is also observed in other areas of technological development, as shown by Juracka et al. (2025), who document substantial differences in innovation and environmental performance across EU member states.

Figure 1: Hierarchical clustering of EU economies based on digital-economic indicators



Source: own elaboration

The combined regression and cluster results highlight substantial heterogeneity in the economic returns to digitalization across EU economies. While the baseline model does not reveal a statistically significant average effect of digital intensity on sectoral value added, the heterogeneous country-specific specification demonstrates that digitalization generates stronger productivity gains in certain national contexts. The cluster analysis further confirms that EU economies can be grouped into distinct digital-economic profiles reflecting differences in digital adoption, economic structure and productivity dynamics. These findings indicate that the economic benefits of digitalization are uneven and strongly conditioned by national and sectoral structural factors, contributing to the broader debate on digital divides within the EU. From a policy perspective, these findings suggest that digitalization strategies should be differentiated across coun-

tries, considering national structural conditions and sectoral characteristics. From a managerial perspective, firms should consider the specific stage of digital development within their country and sector when designing digital investment strategies, as the expected productivity gains from digitalization may vary substantially across contexts

CONCLUSION

This study examined the relationship between digital intensity and sectoral economic performance across EU economies. Using sector-level panel data and the Digital Intensity Index (DII) as a measure of enterprise digitalization, the analysis investigated whether higher digital intensity is associated with higher sectoral value added and whether these effects vary across countries. The empirical framework combined fixed-effects panel regression with hierarchical cluster analysis to capture both the productivity implications of digitalization and structural differences across EU economies.

The results indicate that digital intensity does not have a statistically significant average effect on sectoral value added once sectoral, country-, and time-specific heterogeneity are controlled for, suggesting that the economic benefits of digitalization are not uniform across sectors and countries. However, the heterogeneous country-slopes specification reveals substantial cross-country variation in digital returns. Positive and statistically significant effects are identified primarily in several smaller or catching-up economies, including Bulgaria, Cyprus, Ireland, Malta, and Romania, indicating that digital adoption may generate stronger marginal productivity gains in contexts where digital technologies are still expanding. The findings also suggest sectoral variation in digitalization effects, with knowledge-intensive and digitally adaptable sectors more likely to benefit than traditional industries, where complementary investments and capabilities may be required.

The cluster analysis further confirms structural heterogeneity across EU economies. The results show that countries form distinct digital-economic clusters characterized by different levels of digital intensity and economic performance. Digitally advanced Northern European economies constitute a group with high digital intensity and strong economic outcomes, whereas several Central and Southern European economies form a more heterogeneous cluster with moderate levels of digitalization. In addition, a group of catching-up economies exhibits relatively stronger marginal productivity gains associated with digitalization. These findings imply that digital transformation in the EU follows differentiated national trajectories rather than a single, uniform development path.

From a policy perspective, the results imply that strategies supporting digital transformation should account for country-specific structural conditions, including sectoral composition, technological readiness, and institutional environments. Targeted investments in digital technologies, digital skills, and infrastructure may therefore yield

particularly strong productivity gains in catching-up economies. From a theoretical perspective, the study contributes to the literature by demonstrating that the relationship between digital intensity and economic performance is heterogeneous and conditioned by both country- and sector-specific characteristics. From a practical perspective, the findings suggest that firms and sectoral managers should align digital investment decisions with sector-specific technological and operational conditions to maximize productivity gains.

Despite these contributions, several limitations should be acknowledged. First, the analysis relies on sector-level data covering a limited period (2022–2024), which constrains the ability to capture longer-term dynamics of digital transformation. Second, the use of aggregated sectoral indicators does not allow the analysis to account for firm-level heterogeneity in digital adoption and productivity effects. Third, the study relies on a single com-

posite indicator of enterprise digitalization (DII), which may not fully capture key dimensions of digital transformation, such as digital skills, organizational capabilities, or the quality of implementation. Future research could extend the analysis by incorporating longer time series, additional indicators of digital transformation, and more granular firm-level data, while also examining the role of complementary factors—such as digital skills, innovation capacity, and institutional quality—in shaping the economic returns to digitalization in Europe.

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AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, D.G.; methodology, D.G.; software, D.G.; validation, D.G.; formal analysis, D.G.; investigation, D.G. and I.V.; resources, D.G. and I.V.; data curation, D.G.; writing-original draft preparation, D.G. and I.V.; writing-review and editing, D.G.; visualization, D.G.; supervision, I.V. All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The datasets used and analyzed during the current study are available from the corresponding author upon reasonable request.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

AI DISCLOSURE

The authors did not use artificial intelligence in preparing this article.

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