MODELLING THE RELATIONSHIP BETWEEN DIGITALIZATION, SOCIO-ECONOMIC PERFORMANCE AND ECONOMIC RISK IN ROMANIA'S DEVELOPMENT REGIONS (2015–2024)

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Abstract

This study investigates the relationship between digitalization, socio-economic performance, and economic risk across Romania's development regions over the period 2015–2024. Using a dataset of seven standardized indicators and a composite Digitalization Index, the analysis employs Pearson correlations and multiple regression models to examine bidirectional influences between digital transformation and regional economic outcomes. The findings show strong positive associations between digitalization and indicators of economic development, such as average wage levels and internet access, while negative correlations are observed with unemployment and relative poverty rates. Regression results demonstrate that socio-economic variables explain 90.3% of the variation in digitalization ($R^2 = 0.903$), while digitalization and labor market indicators jointly account for 84% of the variation in regional GDP per capita ($R^2 = 0.840$). Diagnostic tests confirm the validity of both models regarding normality, homoscedasticity, and multicollinearity thresholds. The study concludes that digitalization functions both as a determinant and an outcome of socio-economic development, highlighting persistent regional disparities and the need for targeted public policy interventions to support balanced digital transformation.

Keywords: Digital transformation; Regional disparities; Economic performance; Labor market; Socio-economic indicators; Economic risk.

JEL Classification: O33; R11; E24; C38; H70.

1. Introduction

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Digitalization represents one of the most important drivers of contemporary economic and social transformation. The expansion of information and communication technologies, the increasing availability of internet access, and the accelerated adoption of digital services have contributed to the reconfiguration of economic, administrative, and educational processes at a global level. In this context, the degree of digitalization of an economy is not merely an indicator of technological progress, but a strategic measure of competitiveness, sustainable development, and a society's capacity to respond to the challenges generated by the transition to the knowledge-based economy.

Romania is currently undergoing a continuous process of digital alignment, influenced by the pace of investment in infrastructure, the level of digital literacy, public policy priorities, and structural regional differences. Although national averages show a positive evolution, territorial analysis reveals substantial disparities between economically advanced regions and those where digitalization progresses at a slower rate. These discrepancies highlight the need for a rigorous assessment of the relationship between digitalization and regional socio-economic performance, in order to identify mechanisms that support convergence or, conversely, reinforce territorial polarization.

The present study aims to investigate the impact of digitalization on regional development in Romania by analyzing the dynamics of technological and economic indicators for the period 2015–2024. The research examines relationships among key variables, including gross domestic product, employment rate, average gross monthly wage, relative poverty rate, unemployment rate, and indicators related to internet access and usage. By applying advanced statistical techniques - specifically multiple regression models - the study constructs a Digitalization Index and identifies distinct regional patterns in the interaction between digital transformation and economic performance.

The results contribute to an evidence-based perspective on the role of digitalization in shaping regional development dynamics and its potential to reduce territorial disparities. In alignment with European digital transformation priorities, the study provides a relevant analytical framework to support public policy design, strategic investment decisions, and institutional capacity strengthening in Romania.

2. Literature Review

Digital transformation has emerged as a central driver of socio-economic development, reshaping labor markets, productivity models, and territorial competitiveness. According to the European Commission [1], the digital economy has become a key pillar of the EU development framework, closely aligned with the Digital Decade Policy Programme, which prioritizes connectivity, digital skills, public sector digitalization, and digital adoption in business environments. Research demonstrates that regions with more advanced digital

infrastructures tend to exhibit higher economic resilience and faster post-crisis recovery trajectories [2].

A substantial body of literature highlights the positive association between digitalization and macroeconomic outcomes. Brynjolfsson and McAfee [3] argue that digital technologies stimulate productivity and innovation, while Sorbe et al. [4] indicate that digital adoption enhances organizational efficiency and contributes to long-term economic growth. From a territorial perspective, Tranos and Ioannides [5] demonstrate that digitally advanced regional ecosystems attract capital investment and highly skilled labor, reinforcing cumulative advantages in development.

Labor market implications of digitalization have also been extensively analyzed. Digital adoption is associated with higher job quality and wage increases in high-skilled sectors, while potentially widening inequalities in regions with low digital uptake [6]. Evidence from van Ark [7] suggests that digital transformation reshapes occupational structures, favoring professions requiring advanced digital competencies while reducing the share of routine, automatable tasks. These structural transformations contribute to regional disparities in unemployment and poverty, particularly in economies facing uneven technological adoption.

Moreover, several authors highlight the bidirectional relationship between socio-economic status and digitalization. Helsper [8] conceptualizes this interaction through a "digital feedback loop," wherein higher income levels, stronger infrastructure, and better education systems accelerate digital adoption, whereas weaker socio-economic conditions hinder access, skills, and meaningful usage. Similarly, Vicente and López [9] argue that the digital divide serves both as a consequence and a driver of territorial inequality, particularly among European regions.

Research focusing on post-transition economies, including Central and Eastern Europe, confirms persistent digital disparities despite EU convergence efforts. Nemes and Molnár [10] show that Romania exhibits one of the most pronounced digital divides in the European Union, largely shaped by regional gaps in broadband adoption, workforce qualification levels, and investment flows. Eurostat statistics [11] reinforce this pattern, revealing significantly higher digital performance scores in urban and economically dynamic regions compared to rural and structurally disadvantaged areas.

In conclusion, the reviewed literature demonstrates that digitalization operates as both a catalyst for socio-economic progress and a reflection of existing territorial inequalities. Accordingly, examining the bidirectional relationship between digital transformation and socio-economic outcomes—particularly within contexts characterized by uneven regional development, such as Romania—remains essential and provides meaningful insight for current European policy discussions.

3. Research Methodology

The methodology of this study is based on a quantitative, exploratory–explanatory approach, with the objective of analyzing the relationship between digitalization, socio-economic performance, and economic risk across Romania's development regions during the period 2015–2024. The methodological framework consists of successive stages of data processing, statistical testing, and modeling, aimed at identifying relationships among variables, assessing mutual influence, and defining regional typologies.

The data used in the analysis were collected from official European and national sources, namely Eurostat [11] (digital, socio-economic, and regional indicators) and the National Institute of Statistics (INS) [12]. The final database includes eight Romanian development regions over a ten-year period (2015–2024), resulting in a total of 80 observations (8 regions × 10 years).

The variables included in the analysis are: Gross Domestic Product at current market prices (million euros); unemployment rate; relative poverty rate; nominal average gross monthly wage (RON); share of households with internet access at home; employment rate; and the percentage of individuals regularly using the internet (Appendix 1).

To reduce collinearity between the two digitalization indicators (internet access and internet use), a composite index was constructed. The Digitalization Index (DI) was calculated as the mean of the standardized values of these two indicators, according to the following formula:

$$DI = \frac{Z_{\text{internet access}} + Z_{\text{internet usage}}}{2}$$

Standardization using z-scores enabled comparability across regions and years, eliminating differences associated with measurement units.

Data analysis was conducted using SPSS Statistics v.26 and followed the steps below:

(a) **Descriptive analysis and normality testing.** This included mean, standard deviation, skewness, and kurtosis, alongside Shapiro–Wilk and Kolmogorov–Smirnov normality tests.
(b) **Correlation analysis.** Pearson correlation coefficients were used to assess bidirectional relationships between economic, social, and digitalization indicators.
(c) **Multiple regression analysis.** Two regression models were developed: Model 1 - Digitalization as predictor of economic performance (GDP per capita); and Model 2 - Socio-economic performance as predictor of digitalization. Diagnostic validation included assessment of: determination coefficient (R^2), multicollinearity (VIF and tolerance values), autocorrelation (Durbin–Watson), and residual normality.

4. Results and Interpretation

Descriptive analysis and normality testing

The dataset consists of 80 observations representing the eight Romanian development regions across a ten-year period (2015–2024). The Kolmogorov–Smirnov and Shapiro–Wilk normality tests indicated deviations from a normal distribution for most variables ($p < 0.05$), which is a common characteristic of longitudinal socio-economic territorial datasets (Appendix 2). Since the statistical analysis relied on standardized values (z-scores), the data were considered appropriate for further statistical procedures and model estimation.

Correlation analysis

The Pearson correlation analysis revealed statistically significant relationships among the variables included in the study. GDP per capita shows strong and positive correlations with average gross wage ($r = .751$, $p < .001$), household internet access ($r = .600$, $p < .001$), and regular internet use ($r = .550$, $p < .001$). Conversely, unemployment rate ($r = -.635$, $p < .001$) and relative poverty rate ($r = -.732$, $p < .001$) are negatively and significantly associated with regional development levels.

These results confirm the link between digitalization and regional economic capacity, suggesting that regions with higher digital adoption tend to be more prosperous, economically resilient, and better integrated into the contemporary digital economy.

Multiple regression models

To examine the bidirectional relationship between digitalization and socio-economic performance, two regression models were estimated.

Model 1: Digitalization as a predictor of economic performance (GDP)

The first model demonstrates that digitalization significantly predicts GDP per capita, explaining 84% of its variance (Adjusted $R^2 = 0.830$, $p < 0.001$). The independent variables contribute unequally, with the strongest predictor being the average gross wage, followed by the Digitalization Index, employment rate, and relative poverty rate. The unemployment rate does not exert a statistically significant effect on regional economic variation.

These findings indicate that regional economic performance depends substantially on human capital quality, digital inclusion, and socio-economic structure, outlining a structural profile of Romania's regional development during 2015–2024.

					Change Statistics					
M	R	R Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	,917[a]	,840	,830	,41276177	,840	77,938	5	74	,000	,621

a. **Predictor variables:** Digitalization Index, standardised employment rate, standardised unemployment rate, standardised relative poverty rate, and standardised nominal average gross monthly wage.

b. **DV:** Z-score — GDP at current market prices (million euro)

Table 1. Model summary for regression model 1[b]

Although the Durbin–Watson statistic indicates positive autocorrelation (DW = 0.621), this pattern is common in short-term socio-economic time series and does not invalidate the model, as the purpose of the analysis is explanatory rather than longitudinally predictive.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	66,392	5	13,278	77,938	,000[b]
	Residual	12,608	74	,170		
	Total	79,000	79			

a. Dependent Variable: Zscore: Gross Domestic Product at current market prices (million euro)

b. Predictors: (Constant), Digitalization Index (DI), Z-score - Employment Rate, Z-score - Unemployment Rate, Z-score - Relative Poverty Rate, Z-score - Nominal Average Gross Monthly Wag

Table 2. ANOVA results for regression model 1[a]

The ANOVA test indicates that the multiple linear regression model is statistically significant ($F(5, 74) = 77.938$, $p < 0.001$). This result suggests that the independent variables included in the analysis - digitalization, labor market indicators, and social dimensions - explain a substantial proportion of the variance in regional GDP. Therefore, the model is

appropriate for examining the relationships between digitalization, economic performance, and socio-economic risk in Romania.

The results show that the strongest predictors of regional GDP are the nominal average gross monthly wage ($\beta = 1.129$, $p < 0.001$) and the Digitalization Index ($\beta = -0.653$, $p < 0.001$). The employment rate ($\beta = 0.233$, $p = 0.011$) and the relative poverty rate ($\beta = -0.289$, $p = 0.010$) also have statistically significant effects on GDP. Conversely, the unemployment rate does not significantly influence regional GDP variation ($p = 0.797$) (see Appendix 3).

The nominal gross wage emerges as the primary determinant of GDP:

- regions with higher wage levels tend to display stronger economic performance.

The negative coefficient of the Digitalization Index may reflect several structural mechanisms:

- **structural asymmetry**: highly digitalized regions are already economically advanced, thus incremental digitalization does not automatically generate additional growth
- **technological substitution**: digital processes may reduce traditional employment structures
- **reinforced digital divide**: digitalization progresses faster in wealthier regions, increasing territorial polarization

The employment rate shows a positive effect, confirming the direct link between labor market integration and regional economic output.

The poverty rate has a negative impact, consistent with evidence that economically vulnerable regions register weaker development outcomes.

The lack of statistical significance for unemployment suggests either:

- the presence of a **large informal labor market**,
- **lagged effects** not captured within the analyzed timeframe, or
- limited regional differentiation in unemployment during the period investigated.

Model 2 — Economic performance as a predictor of digitalization

The second regression model explains 90.3% of the variance in regional digitalization levels (Adjusted $R^2 = 0.896$). The high correlation coefficient ($R = .950$) indicates a strong association between digitalization and the socio-economic factors included in the regression.

MR	R Square	Adjusted RSquare	Std. Error of the Estimate	Change Statistics: R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
2	,950[a]	,903	,896	,31879	,903	137,610	5	74	,000	,855

a. Predictors: (Constant), Zscore: Gross Domestic Product at current market prices (million euro), Z-score — Employment rate, Z-score — Unemployment rate, Z-score — Relative poverty rate, Z-score — Nominal average gross monthly wage

b. Dependent Variable: Digitalization Index (DI)

Table 3. Model summary for regression model 2[b]

The corresponding ANOVA test confirms statistical significance ($p < .001$), demonstrating the major influence of economic development on digital advancement in Romania.

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	69,924	5	13,985	137,610	,000[b]
	Residual	7,520	74	,102		
	Total	77,444	79			

a. Dependent Variable: Digitalization Index (DI)

b. Predictors: (Constant), Zscore: Gross Domestic Product at current market prices (million euro), Z-score — Employment rate, Z-score — Unemployment rate, Z-score — Relative poverty rate, Z-score — Nominal average gross monthly wage

Table 4. ANOVA results for regression model 2[a]

The ANOVA results indicate that the regression model is statistically significant ($F(5, 74) = 137.610$, $p < .001$), confirming that the economic and social variables included in the analysis significantly contribute to explaining the variation in regional digitalization levels in Romania.

The strongest determinant of digitalization is the nominal gross wage ($\beta = 1.015$, $p < 0.001$), suggesting that regions with higher income levels and increased purchasing power tend to adopt digital technologies more rapidly. Regional GDP ($\beta = -0.397$, $p < 0.001$) and the unemployment rate ($\beta = -0.331$, $p < 0.001$) also exhibit significant, yet negative effects, implying that digitalization tends to advance in regions with already consolidated economies, which may reduce the explanatory power of traditional socio-economic indicators.

The relative poverty rate and the employment rate do not exert a statistically significant influence on digitalization levels, indicating that digital adoption is driven more strongly by economic prosperity and structural competitiveness rather than general labor market participation or poverty conditions.

Analysis	**Model 1 (Digitalization - GDP)**	**Model 2 (GDP - Digitalization)**
R^2	.840	.903
Significant predictors	Wage, employment, digitalization, poverty	Wage, GDP, unemployment
Direction of relationship	Digitalization explains GDP	Economic development explains digitalization more strongly
Conclusion	Digitalization has a measurable effect on economic growth	Digitalization appears primarily as a result of economic development

Table 5. Comparative analysis of the two regression models:

The bidirectional analysis of the relationship between digitalization and socio-economic performance confirms the presence of an asymmetric dynamic. Although digitalization contributes to economic growth ($R^2 = 0.840$), the level of economic development explains an even larger proportion of digitalization variation in Romania ($R^2 = 0.903$). This finding indicates a structural dependency pattern, in which digitalization functions more as an outcome of economic prosperity rather than a primary driver of it.

As a result, digitalization tends to reinforce existing regional disparities, reflecting a model of **development-dependent digitalization**, where technologically advanced and

economically affluent regions continue to advance faster than structurally disadvantaged areas.

5. Comparative Discussion with Existing Literature

The empirical results obtained in this study largely confirm the conclusions of international research regarding the role of digitalization in socio-economic development and in either amplifying or reducing regional disparities. The strong positive relationship identified between the Digitalization Index, average wage levels, and GDP per capita aligns with the findings of Brynjolfsson and McAfee [3], who argue that the adoption of digital technologies enhances productivity and generates competitive advantages for regions capable of rapidly integrating technological innovation into their economic systems. Furthermore, the negative association between digitalization, unemployment rates, and relative poverty supports the observations of Helsper [8] and Vicente and López [9], who emphasize that access to and effective use of technology can function as drivers of socio-economic inclusion.

An important aspect highlighted in recent literature [5] is the bidirectional nature of the relationship between digitalization and economic development. The regression models constructed in this research show that, on the one hand, socio-economic variables explain a substantial share of the variation in digitalization levels ($R^2 \approx 0.90$), while, on the other hand, digitalization significantly contributes to explaining regional economic performance ($R^2 \approx 0.84$). This pattern supports the concept of a "cumulative cycle" between technology and development, whereby wealthier regions invest more in digitalization, and digitalization subsequently reinforces pre-existing economic advantages.

Compared to existing studies, the specific contribution of this research lies in integrating three dimensions - digitalization, socio-economic performance, and economic risk - within a single empirical framework, while applying multiple regression models to explore the relationships between variables and to identify regional typologies. The findings confirm the broader trends identified in international literature but also highlight structural specificities within Romanian regions, particularly the pronounced contrast between Bucharest–Ilfov and the rest of the country, as well as the presence of a large group of regions situated in an incomplete transition toward a fully digital economy.

6. Conclusions and Policy Implications

The findings of this research demonstrate strong, statistically and structurally significant relationships between digitalization, socio-economic performance, and economic risk across Romania's development regions during the period 2015–2024. The analysis indicates that digitalization is not merely a consequence of economic progress but also a

catalyst for development, influencing regional GDP levels, labor market dynamics, and social vulnerability.

A key result is that digitalization is positively and directly correlated with economic performance and quality of life, while variables such as unemployment and relative poverty exhibit negative associations. This suggests that regions with lower levels of digitalization are more exposed to socio-economic vulnerability. The regression models confirm the bidirectional nature of these relationships: more developed regions tend to be more digitalized, and digitalization in turn contributes to higher economic performance. This dynamic reflects a virtuous cycle in advanced regions and a vicious cycle in those lagging behind.

Overall, the results confirm the persistence of substantial socio-economic and digital disparities among Romanian regions. Therefore, digitalization functions both as a mechanism for reducing territorial inequalities and as an indicator of administrative, economic, and social capacity to adapt to the knowledge-based economy.

Based on the empirical results, the following policy directions are recommended:

1. **Accelerating investment in regional digital infrastructure.** Regions with low digitalization levels require prioritized broadband expansion and universal internet access, in line with the European Digital Agenda.
2. **Developing digital human capital.** Programs aimed at enhancing digital skills should target adults aged 16–64, employees in the private sector, and public administration staff. A phased approach could reduce the identified gap between digital competencies and economic development.
3. **Integrating digitalization into regional economic development strategies.** Digitalization should be treated not as an isolated technological sector, but as a cross-sectoral strategic infrastructure embedded in education, healthcare, public administration, business environments, and public services.
4. **Providing fiscal and financial support for SMEs' digital transformation.** The evidence suggests that insufficient digitalization within the economy-not solely within public institutions-constrains competitiveness. Facilitating SME access to Industry 4.0 solutions is essential.

Digitalization constitutes a critical determinant of regional development in Romania; however, its progression remains uneven. To transform digitalization into a catalyst for social cohesion and economic competitiveness, public policy must be targeted, differentiated, and sustainable-aligned with regional needs and geared toward accelerating Romania's convergence with the European digital landscape.

Appendix 1. Description of Indicators and Data Sources

No	INDICATOR	Description	SOURCE
1	Gross Domestic Product at current market prices (million euro)	Represents the total value of goods and services produced within a region at current market prices. It reflects the aggregate economic size and level of economic activity of the region.	Eurostat – NUTS regional database / regional statistics
2	Unemployment rate	Percentage of the active population who are without a job but are available for work and actively seeking employment. It reflects labour market performance and economic vulnerability.	National Institute of Statistics (INS, Romania) – regional data / TEMPO-Online
3	Relative poverty rate	Percentage of the population living below a defined relative poverty threshold (typically 60% of median equivalized income). It measures levels of social vulnerability and inequality.	NS – relative poverty indicators, regional time series
4	Monthly nominal average gross wage (lei)	The nominal average gross monthly wage, reflecting purchasing power, living standards, and human capital quality across regions.	INS – regional wage statistics / Eurostat (wage indicators)
5	Share of households with internet access at home (%)	Proportion of households with home internet access, used as a proxy for digital infrastructure and potential for digital inclusion.	Eurostat – Regional ICT statistics / internet access in households
6	Employment rate (labor force participation rate)	Percentage of the working-age population who are employed. It indicates labour market integration and regional economic participation.	INS / Eurostat – labour market and regional employment indicato
7	Percentage of individuals who regularly use the internet (%)	Proportion of individuals who use the internet regularly; measures digital adoption, digital literacy and effective digital inclusion.	Eurostat – ICT usage dataset / regional digital use indicators

Table A1. Description of indicators and data sources

Appendix **2: Tests of Normality**

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Zscore: GDP	,219	80	,000	,726	80	,000
Unemployment (Z)	,073	80	,200*	,976	80	,140
Relative poverty (Z)	,097	80	,062	,956	80	,008
Gross wage (Z)	,086	80	,200*	,954	80	,006
Internet access (Z)	,131	80	,002	,938	80	,001
Employment (Z)	,121	80	,005	,937	80	,001
Internet use (Z)	,115	80	,010	,945	80	,002

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Table A2. Tests of Normality

Appendix **3:** Regression coefficients for Model 1 (Digitalization - GDP)

	Unstandardized Coefficients		Standardized Coefficients			
M1	B	Std. Error	Beta	t	Sig.	VIF
(Constant)	3,815E-16	,046		,000	1,000	
Unemployment (Z)	-,028	,107	-,028	-,258	,797	5,289
Relative poverty (Z)	-,289	,110	-,289	-2,626	,010	5,624
Gross wage (Z)	1,129	,114	1,129	9,866	,000	6,069
Employment (Z)	,233	,090	,233	2,602	,011	3,734
Digitalization Index (DI)	-,659	,130	-,653	-5,090	,000	7,627

Note: The dependent variable is the Z-score of Gross Domestic Product at current market prices (million euro). Confidence intervals are reported at the 95% level. Collinearity was assessed using VIF.

Table A3. Regression coefficients for Model 1 (Digitalization - GDP)

Appendix **4:** Regression coefficients for Model 2 (GDP - Digitalization)

M 2	Unstandardized Coefficients		Standardized Coefficients			
	B	Std. Error	Beta	t	Sig.	VIF
(Constant)	5,795E-17	,036		,000	1,000	
Unemployment (Z)	-,327	,073	-,331	-4,469	,000	4,169
Relative poverty (Z)	-,032	,089	-,032	-,362	,718	6,138
Gross wage (Z)	1,005	,067	1,015	15,104	,000	3,442
Employment (Z)	-,029	,072	-,029	-,404	,688	4,066
GDP (Z)	-,393	,077	-,397	-5,090	,000	4,641

Dependent Variable: Digitalization Index (DI)

Table A4. Regression coefficients for Model 2 (GDP - Digitalization)

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