

Emilia ȚÎȚAN, PhD

emilia.titan@csie.ase.ro

Bucharest University of Economic Studies; Bucharest, Romania

Andreea Oana ENACHE, PhD

andreea.begu@csie.ase.ro

Bucharest University of Economic Studies; Bucharest, Romania

Ioana Teodora MEȘTER, PhD (corresponding author)

imester@uoradea.ro

University of Oradea; Oradea, Romania

Ioana VIAȘU, PhD

ioana.viasu@e-uvvt.ro

West University of Timisoara; Timisoara, Romania

Andreea Mihaela STROE, PhD

andreea.stroe@unibuc.ro

University of Bucharest, Bucharest, Romania

Determinants of Digital Infrastructure Development in European Countries: A Dynamic Panel Data Approach

Abstract. *This study investigates the determinants of digital infrastructure development in European countries using a dynamic panel data approach. The empirical analysis is based on a balanced panel dataset covering 35 European countries over the period 2014–2023. Given the cumulative nature of digital infrastructure development and the potential endogeneity of explanatory variables, the model is estimated using the Arellano–Bond Generalized Method of Moments (GMM) estimator. The specification includes a lagged dependent variable together with key economic and social determinants, namely GDP per capita, government expenditure on education, and labour force participation. The results reveal a high degree of dynamic persistence, indicating that current levels of digital infrastructure are strongly influenced by previous levels of development. Economic development and educational investment exert positive and statistically significant effects, highlighting the importance of financial resources and human capital in supporting digital transformation. Labour force participation displays a positive but weaker effect. Diagnostic tests confirm the validity of the instruments and the adequacy of the dynamic specification. The findings emphasize the need for sustained investment strategies and human capital development to reduce digital disparities and support digital transformation across Europe.*

Keywords: *digital infrastructure, dynamic panel data, Generalized Method of Moments (GMM), Arellano–Bond estimator, economic development, education expenditure, labour force participation, European countries.*

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1. Introduction

Digital transformation has become one of the most important drivers of economic and social change in contemporary economies. Advances in information and communication technologies (ICT), broadband connectivity, cloud computing, artificial intelligence, and digital platforms have significantly reshaped production processes, labour markets, public administration, and patterns of social interaction. In this context, digital infrastructure has emerged as a fundamental component of economic and social development, contributing to productivity growth, innovation, competitiveness, and access to information and digital services.

Within the European context, the development of digital infrastructure has been strongly supported by strategic initiatives and public policies aimed at accelerating digital transformation and reducing technological disparities among countries. The growing importance of digital technologies in sectors such as education, public administration, healthcare, and financial services has further increased the need for modern and efficient digital infrastructure. Despite substantial progress achieved in recent years, significant differences in digital development continue to exist across European countries, highlighting the importance of identifying the factors that influence the expansion of digital infrastructure and the mechanisms through which these factors operate.

From a theoretical perspective, digital infrastructure development results from the interaction of economic, social, institutional, and technological factors. Economic development, commonly measured through GDP per capita, influences the capacity of governments and private actors to finance investments in technological infrastructure. At the same time, human capital plays a crucial role in supporting digital transformation, as education and skills determine the ability of individuals and organizations to adopt and effectively utilize digital technologies. Labour market characteristics may also influence the demand for digital services and the pace of technological adoption. In addition, recent studies have highlighted that broader demographic processes including migration may indirectly affect digital development through their impact on labour markets, human capital accumulation, and demand for digital services.

The analysis of these relationships requires econometric approaches capable of capturing the dynamic nature of digital infrastructure development. Unlike many economic and social phenomena characterized by rapid adjustment processes, digital infrastructure evolves gradually through cumulative investments and technological accumulation. Current levels of digital development are therefore strongly influenced by previous achievements, making it necessary to account for persistence effects when investigating the determinants of digital infrastructure.

Against this background, the main objective of the present study is to identify and evaluate the economic and social determinants of digital infrastructure development in European countries. More specifically, the analysis investigates the

influence of GDP per capita, government expenditure on education, and labour force participation on digital infrastructure development using a dynamic panel data model estimated through the Arellano–Bond Generalized Method of Moments (GMM) approach. The study covers a balanced panel of 35 European countries over the period 2014–2023.

The value added of this study lies primarily in its dynamic approach to the analysis of digital infrastructure development. While previous studies have extensively examined the relationship between digitalization, economic development, human capital, and institutional factors, comparatively less attention has been devoted to the persistence of digital infrastructure development over time and to the simultaneous assessment of its economic and social determinants within a dynamic panel framework. By incorporating the lagged dependent variable and applying the Arellano–Bond GMM estimator, the study explicitly accounts for the path-dependent nature of digital infrastructure development while addressing the endogeneity generated by the dynamic specification. In addition, the analysis covers a heterogeneous sample of 35 European countries over the 2014–2023 period, allowing differences in levels of economic development and socioeconomic conditions to be incorporated within a common empirical framework. The study therefore contributes to existing literature by providing evidence on the extent to which previous levels of digital development, economic performance, educational investment, and labour market participation jointly shape the evolution of digital connectivity across European countries.

The remainder of the paper is organized as follows. Section 2 reviews the relevant literature on the determinants of digital infrastructure development. Section 3 presents the data, variables, and econometric methodology. Section 4 discusses empirical results. Section 5 outlines the limitations of the study and proposes directions for future research. Finally, Section 6 concludes the paper.

2. Literature Review

The development of digital infrastructure has become one of the key dimensions of economic modernization and digital transformation. The existing literature suggests that differences in digital infrastructure across countries are determined by a combination of economic, educational, institutional, demographic, and technological factors. Although the relative importance of these determinants varies across studies, there is broad agreement that digital infrastructure development is a multidimensional process that reflects both economic capacity and societal readiness for technological adoption.

A substantial body of research identifies economic development as a fundamental driver of digital infrastructure expansion. Countries characterized by higher levels of GDP per capita generally possess greater financial resources for investments in broadband networks, information and communication technologies (ICT), and advanced digital services. Empirical evidence provided by Niebel (2018) and Vu et al. (2020) indicates that economic prosperity facilitates technological

modernization and supports the diffusion of digital technologies across sectors of the economy. These findings suggest that economic growth and digital infrastructure development reinforce each other through mutually beneficial feedback mechanisms. Recent evidence from European Union member states further confirms the importance of technological infrastructure, human capital, and innovation capacity in explaining differences in digital development outcomes across countries (Roszko-Wójtowicz et al., 2024).

Another important strand of literature emphasizes the role of human capital and education in supporting digital transformation. Investments in education contribute to the development of digital competencies, increase the capacity of individuals and organizations to adopt new technologies, and enhance the productivity effects associated with ICT investments. Cardona et al. (2013) argue that the economic benefits of digital technologies depend significantly on the quality of human capital, while Sorgner et al. (2017) highlight the growing importance of digital skills in increasingly technology-intensive labour markets. Consequently, education represents not only a social investment but also a critical determinant of digital infrastructure utilization and effectiveness. More recent studies conducted at the European level further support the view that digital skills and educational attainment contribute significantly to the effective utilization of digital infrastructure and the development of entrepreneurial activity within the digital economy (Dzitac et al., 2026).

Institutional quality and public policies constitute another important group of determinants identified in the literature. Baller et al. (2016) show that countries characterized by effective governance, lower levels of corruption, and stronger administrative capacity tend to achieve higher levels of digital development. Similarly, Sabatini and Sarracino (2020) emphasize the importance of institutional environments that facilitate technological adoption and innovation. At the European level, public policies promoting digital convergence and innovation have been identified as important mechanisms for reducing regional disparities and accelerating digital transformation (Crespo Cuaresma & Lutz, 2021; Zeinali & Mussari, 2025). Recent analyses also emphasize the growing importance of Digital Decade objectives and coordinated European policies aimed at enhancing digital competitiveness, connectivity, and technological resilience across member states (European Commission, 2025; Manganelli, 2025). Nevertheless, recent evidence suggests that important disparities persist among European countries regarding digital readiness, technological adoption, and digital public service development, indicating that the benefits of digital transformation remain unevenly distributed across the European Union (Valaskova, 2025).

Recent research has increasingly focused on the role of demographic factors, particularly migration, in shaping digital development. Population mobility may influence the geographical distribution of demand for digital services, modify labour market structures, and affect the fiscal capacity of governments to finance infrastructure investments. Biagi et al. (2018) argue that migration flows can generate additional pressure on existing digital infrastructure, while OECD (2023)

highlights the role of skilled migration in facilitating the transfer of digital knowledge and technological capabilities. Furthermore, remittances and transnational networks associated with migration may stimulate digital adoption and connectivity, particularly in emerging European economies (World Bank, 2021). The broader literature on migration and human capital also suggests that labour mobility can influence the diffusion of technological innovation and contribute to regional differences in digital development (Bertoli & Moraga, 2013; Czaika & Parsons, 2017).

From a methodological perspective, empirical studies investigating the determinants of digitalization frequently employ panel data techniques, as these approaches allow researchers to exploit both the cross-sectional and temporal dimensions of the data. However, a significant part of the existing literature relies on static panel specifications, which may not adequately capture the cumulative and path-dependent nature of digital infrastructure development. Since digital infrastructure is largely influenced by previous investments, institutional accumulation, and technological trajectories, current levels of development are expected to depend strongly on past achievements.

This argument is supported by studies employing dynamic panel methodologies. Katz and Callorda (2018), as well as Salahuddin and Alam (2016), provide empirical evidence suggesting that digital development exhibits substantial persistence over time, thereby justifying the use of dynamic econometric specifications. Dynamic panel models estimated through the Generalized Method of Moments (GMM) offer important advantages by allowing researchers to account for lagged effects, control for unobserved heterogeneity, and address potential endogeneity issues.

Despite the growing literature on digital transformation, relatively limited attention has been devoted to examining the determinants of digital infrastructure development within a dynamic framework covering a broad sample of European countries. Moreover, existing studies often focus either on economic determinants or on institutional and technological factors separately. Therefore, there remains scope for a more integrated analysis that simultaneously considers economic development, education, labour market participation, and the dynamic persistence of digital infrastructure.

Against this background, the present study contributes to the literature by investigating the determinants of digital infrastructure development in 35 European countries during the period 2014–2023 using a dynamic panel data model estimated through the Arellano–Bond GMM approach. By explicitly accounting for the cumulative nature of digital infrastructure development and by jointly examining the roles of economic development, education expenditure, and labour force participation, the study provides additional empirical evidence regarding the mechanisms underlying digital transformation in Europe.

3. Model Specification

3.1 Data and Variables

The empirical analysis is based on a balanced panel dataset covering 35 European countries over the period 2014–2023. The selection of countries was determined by data availability and the need to maintain a consistent time series for dynamic panel estimation. We collected data from Eurostat, World Bank Open Data, OECD Statistics, and international reports on digitalization.

The dependent variable (INFR) is measured using the World Bank indicator "Individuals using the Internet (% of population)" (IT.NET.USER.ZS). The indicator represents the percentage of individuals who have used the Internet during the previous three months. Although the indicator does not directly measure digital infrastructure, it is widely used as a proxy for digital development and connectivity, reflecting the extent to which the population is able to access and utilize digital communication networks and services.

The explanatory variables included in the model are:

- GDP per capita (GDP), measured in purchasing power parity terms, used as a proxy for the level of economic development;
- Government expenditure on education (EDU), expressed as a percentage of GDP, reflecting investments in human capital;
- Labour force participation rate (LABOUR), included to capture labour market dynamics and the potential demand for digital technologies.

The linear correlation coefficients between the variables included in the analysis are presented in the following table:

Table 1. Correlation matrix

Probability	INFR	GDP	EDU	LABOR
INFR	1			
GDP	0.7269	1		
EDU	0.4758	0.1842	1	
LABOR	0.5298	0.3538	0.5567	1

Source: own computations in Eviews based on data collected from the World Bank.

The linear correlation coefficients indicate significant positive associations ($p < 0.0001$) between INFR and the other variables included in the analysis. For the logarithmically transformed data, the linear correlation coefficients retain the same signs and levels of statistical significance, while their magnitudes remain very similar.

To account for the dynamic nature of digital infrastructure development, the lagged dependent variable is included among the regressors. All variables are expressed in natural logarithms, allowing the estimated coefficients to be interpreted as elasticities.

3.2 Dynamic Panel Model Specification

The analysis of digital infrastructure determinants requires an econometric framework capable of capturing both the persistence of digital development and the potential endogeneity of explanatory variables. Digital infrastructure is inherently cumulative, as current levels of development are strongly influenced by past investments, technological capabilities, and institutional conditions. Consequently, a static panel specification may fail to adequately represent the dynamic adjustment process underlying digital infrastructure development.

To account for these characteristics, the present study employs a dynamic panel data model that includes a lagged dependent variable among the regressors. The inclusion of the lagged dependent variable allows the model to capture the persistence and path-dependent nature of digital infrastructure development across European countries.

The general specification of the model is as follows:

$$\ln(INFR_{it}) = \alpha \ln(INFR_{i,t-1}) + \beta_1 \ln(GDP_{it}) + \beta_2 \ln(EDU_{it}) + \beta_3 \ln(LABOUR_{it}) + \mu_i + \varepsilon_{it}$$

where:

- $INFR_{it}$ denotes the level of digital infrastructure in country i during year t ;
- $INFR_{i,t-1}$ represents the lagged value of digital infrastructure;
- GDP_{it} is GDP per capita;
- EDU_{it} denotes government expenditure on education as a percentage of GDP;
- $LABOUR_{it}$ represents the labour force participation rate;
- μ_i captures country-specific unobserved effects;
- ε_{it} is the idiosyncratic error term.

Because all variables are expressed in natural logarithms, the estimated coefficients may be interpreted as elasticities.

3.3 Estimation Procedure

The inclusion of a lagged dependent variable creates a correlation between the regressors and the error term, rendering conventional fixed-effects and random-effects estimators inconsistent. To address this issue, the model is estimated using the Generalized Method of Moments (GMM) estimator proposed by Arellano and Bond (1991).

The Arellano–Bond estimator eliminates country-specific fixed effects through first differencing and employs lagged levels of endogenous variables as internal instruments. This approach is particularly appropriate in situations characterized by a relatively large number of cross-sectional units and a limited time dimension, as is the case in the present study ($N = 35$, $T = 10$). From an economic standpoint, the coefficient of the lagged dependent variable captures the degree of persistence characterizing the analysed phenomenon, as well as the speed at which the system converges toward its long-run equilibrium (Jula & Jula, 2019, pp. 219-231).

The first-difference transformation yields the following equation:

$$\Delta \ln(INFR_{it}) = \alpha \Delta \ln(INFR_{i,t-1}) + \beta_1 \Delta \ln(GDP_{it}) + \beta_2 \Delta \ln(EDU_{it}) + \beta_3 \Delta \ln(LABOUR_{it}) + \Delta \varepsilon_{it}$$

In the preceding equation, the variable $\ln(INFR_{i,t-1})$ contains $\varepsilon_{i,t-1}$. Consequently, after first differencing, $\Delta \ln(INFR_{i,t-1})$ is correlated with $\Delta \varepsilon_{it}$. Therefore, the exogeneity condition for the explanatory variables is violated, implying that OLS estimators are inconsistent. To address this endogeneity problem, the Arellano–Bond GMM methodology is employed. The Arellano–Bond approach relies on the observation that sufficiently lagged values of $\ln(INFR_{it})$ are uncorrelated with subsequent error terms. In particular, $\ln(INFR_{i,t-2})$ is assumed to be uncorrelated with both ε_{it} and $\varepsilon_{i,t-1}$, while remaining correlated with $\Delta \ln(INFR_{i,t-1})$, since:

$$\Delta \ln(INFR_{i,t-1}) = \ln(INFR_{i,t-1}) - \ln(INFR_{i,t-2})$$

Hence, values of the dependent variable lagged two periods or more can be used as valid internal instruments in the GMM estimation, under the standard Arellano–Bond moment conditions.

4. Empirical Results

4.1 Diagnostic Tests and Model Validation

Before interpreting the estimated coefficients, it is necessary to assess the validity of the econometric specification. The Hansen–Sargan test of overidentifying restrictions yields a p-value of 0.3216, indicating that the null hypothesis of instrument validity cannot be rejected. Consequently, the instruments used in the GMM estimation appear to be appropriate and uncorrelated with the error term.

The Arellano–Bond serial correlation tests provide additional support for model validity. As expected in first-difference estimations, first-order serial correlation is weakly present. More importantly, the AR(2) test produces a p-value of 0.9815, indicating the absence of second-order serial correlation in the differenced residuals. This result supports the validity of the lagged instruments and confirms the adequacy of the dynamic specification.

The residual distribution was examined using the Jarque–Bera test. The results indicated deviations from normality, mainly due to the presence of several outliers, particularly for Moldova and, to a lesser extent, Croatia and Italy. Rather than excluding these observations, the analysis employed the Two-Step Arellano–Bond GMM estimator with White period weighting and White period (cross-section cluster) covariance correction, which provides robust estimates in the presence of heteroskedasticity and outliers. Moreover, the asymptotic properties of the GMM estimator ensure consistency and efficiency in sufficiently large samples, even when the normality assumption for the error term is violated.

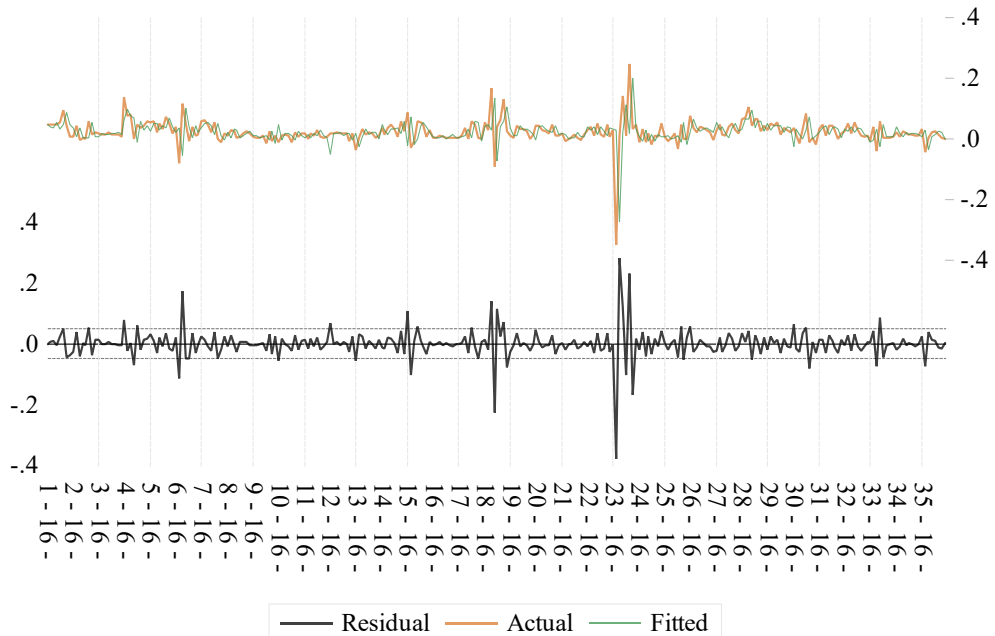


Figure 1. Residuals of the estimated GMM model

Source: own computations in Eviews based on data collected from the World Bank.

Cross-sectional dependence was also examined prior to model estimation. Since post-estimation cross-section dependence tests are not directly available for the Arellano–Bond estimator due to the first-difference transformation, the tests were performed on the differenced dependent variable, $\ln(\text{INFR})$, corresponding to the series used in the GMM estimation procedure. The results are summarized in Table 2.

Table 2. Cross-Section Dependence Tests

Test	Statistic	d.f.	Prob.
Breusch-Pagan LM	644.5062	595	0.0783
Pesaran scaled LM	1.435114		0.1513
Bias-corrected scaled LM	-0.752386		0.4518
Pesaran CD	1.933746		0.0531

Source: own computations in Eviews based on data collected from the World Bank.

The Breusch–Pagan LM, Pesaran scaled LM, Bias-corrected scaled LM, and Pesaran CD tests do not reject the null hypothesis of cross-sectional independence at conventional significance levels. These findings suggest that cross-sectional dependence is not a significant concern in the analysed panel and provide additional support for the application of the Arellano–Bond GMM estimator.

Overall, the diagnostic tests suggest that the estimated model provides a statistically reliable framework for investigating the determinants of digital infrastructure development in European countries.

4.2 Estimation Results and Discussion

The coefficient associated with the lagged dependent variable is equal to 0.784 and is highly significant statistically ($p < 0.001$). This result provides strong evidence of dynamic persistence in digital infrastructure development across European countries.

The estimated coefficient suggests that approximately 78% of the current level of digital infrastructure can be explained by the previous year's level, highlighting the cumulative nature of technological investments. Digital infrastructure development therefore appears to be characterized by substantial inertia, as current achievements depend heavily on past investments, institutional capacity, and technological accumulation.

Table 3. GMM Estimation Results

Variable	Coefficient	Std. Error	t-Statistic	Prob.
ln(INFR(-1))	0.784152	0.007014	111.7950	0.0000
ln(GDP)	0.074573	0.002951	25.27110	0.0000
ln(EDU)	0.032576	0.006614	4.925418	0.0000
ln(LABOUR)	0.071594	0.042427	1.687476	0.1007
Effects Specification				
Cross-section fixed (first differences)				
Mean dependent var	0.021664	S.D. dependent var		0.039286
S.E. of regression	0.049624	Sum squared resid		0.679651
J-statistic	34.08226	Instrument rank		35
Prob(J-statistic)	0.321576			

Source: own computations in Eviews based on data collected from the World Bank.

From an economic perspective, the coefficient remains below unity, indicating a stable dynamic process and gradual convergence toward a long-run equilibrium. However, the relatively high magnitude of the coefficient suggests that the adjustment process is slow, reflecting the capital-intensive nature of digital infrastructure investments.

GDP per capita exerts a positive and statistically significant effect on digital infrastructure development. The estimated elasticity of 0.075 indicates that a 1% increase in GDP per capita is associated with an average increase of approximately 0.075% in digital infrastructure, *ceteris paribus*.

This result confirms the central role of economic development in supporting digital transformation. Economies characterized by higher income levels generally possess greater financial resources, stronger institutional capacities, and increased investment potential, all of which facilitate the expansion and modernization of digital infrastructure.

The finding is consistent with previous studies emphasizing the close relationship between economic prosperity and technological development. It also suggests that policies aimed at stimulating economic growth may generate indirect benefits through the expansion of digital infrastructure and the acceleration of digital transformation processes.

Government expenditure on education also exhibits a positive and statistically significant impact on digital infrastructure development. The estimated elasticity of 0.033 suggests that increases in educational investment contribute positively to the expansion of digital infrastructure.

Although the magnitude of the coefficient is smaller than that associated with GDP per capita, the result highlights the importance of human capital in supporting digital transformation. Digital infrastructure can generate substantial economic and social benefits only when accompanied by a workforce capable of adopting and effectively utilizing digital technologies.

The positive relationship identified in the model supports the view that educational policies and digital infrastructure investments should be considered complementary rather than independent dimensions of development strategy.

The labour force participation rate displays a positive coefficient, although its statistical significance is weaker compared to the other explanatory variables. While the estimated elasticity suggests that higher participation rates may contribute to digital infrastructure development, the evidence remains relatively limited.

One possible explanation is that quantitative labour market participation alone does not necessarily translate into increased demand for advanced digital infrastructure. Instead, the quality of labour, including digital skills, technological competencies, and workforce adaptability, may represent more important determinants of digital transformation than participation rates per se.

This finding suggests that future research should consider incorporating indicators of digital skills and workforce qualification to better capture the labour market dimension of digital development.

5. Limitations and Future Research

Despite the methodological advantages offered by the dynamic panel data model estimated through the Generalized Method of Moments (GMM), the present study is subject to several limitations that should be acknowledged when interpreting the results.

A first limitation relates to the relatively short time dimension of the dataset. Although the period analysed is relevant from the perspective of recent digital transformation processes, digital infrastructure development is inherently a long-term phenomenon characterized by cumulative investments and delayed effects. Consequently, the available time horizon may not fully capture long-run structural relationships and adjustment mechanisms.

A second limitation concerns the selection of explanatory variables. While the model incorporates key economic and social determinants identified in the literature, digital infrastructure development is also influenced by factors that are difficult to quantify or for which comparable data are not consistently available across countries. These include institutional quality, digital governance, regulatory frameworks, innovation capacity, research and development activities, and the quality of digital public services. The omission of such variables may limit the explanatory power of the estimated specification. A further limitation concerns the measurement of digital

infrastructure. The indicator used in the present study, namely the percentage of individuals using the Internet, captures an important dimension of digital connectivity but cannot encompass the multidimensional nature of digital infrastructure. Future research could therefore construct a composite digital infrastructure indicator based on several dimensions of digital development, using Principal Component Analysis (PCA). Such an approach could integrate indicators related to Internet access and use, fixed and mobile broadband connectivity, and other components of digital infrastructure, providing a more comprehensive measure of digital infrastructure development.

Another limitation is associated with the relatively low temporal variability of certain socio-demographic indicators. Certain socio-economic and demographic indicators tend to evolve gradually over time and exhibit limited year-to-year variation within European countries. In the context of a difference-GMM framework, such characteristics may reduce the informational content available for estimation and contribute to statistically insignificant coefficients, even when economically meaningful relationships may exist.

From a methodological perspective, the analysis relies on the Difference GMM estimator proposed by Arellano and Bond (1991). Although the diagnostic tests support the validity of the estimated model, future research could employ the System GMM approach developed by Arellano and Bover (1995) and Blundell and Bond (1998). This methodology may improve estimation efficiency, particularly in the presence of highly persistent variables and limited time dimensions.

Several directions for future research emerge from the present findings. First, extending the dataset both temporally and geographically would allow the investigation of longer-run dynamics and facilitate comparative analyses across groups of countries with different levels of digital maturity. Second, future studies could incorporate institutional, technological, and innovation-related indicators in order to obtain a more comprehensive understanding of the determinants of digital infrastructure development. Third, additional research could explore potential nonlinear relationships, threshold effects, and convergence processes in digital development across European countries. Such extensions would contribute to a deeper understanding of the mechanisms underlying digital transformation and the factors shaping digital infrastructure growth in Europe.

6. Conclusions

The present study examined the determinants of digital infrastructure development in 35 European countries over the period 2014–2023 using a dynamic panel data model estimated through the Arellano–Bond Generalized Method of Moments (GMM) approach. The use of a dynamic specification made it possible to capture the cumulative nature of digital infrastructure development while addressing potential endogeneity issues associated with the explanatory variables.

The empirical findings provide strong evidence of dynamic persistence in digital infrastructure development. The estimated coefficient associated with the lagged dependent variable indicates that current levels of digital infrastructure are

strongly influenced by previous levels of development. This result confirms that digital infrastructure evolves through a gradual accumulation process, reflecting the long-term nature of technological investments, institutional adaptation, and digital transformation strategies. Consequently, improvements in digital infrastructure cannot be achieved through short-term interventions alone but require sustained investment efforts and policy continuity over time.

The results also demonstrate the significant role of economic development in supporting digital infrastructure expansion. GDP per capita exhibits a positive and statistically significant effect, suggesting that countries with higher income levels possess greater financial and institutional capacity to invest in technological modernization. This finding is consistent with the view that economic development and digital transformation are mutually reinforcing processes, with digital infrastructure acting both as a consequence and as a driver of economic growth.

A further important result concerns the role of education. Government expenditure on education was found to have a positive and statistically significant impact on digital infrastructure development, highlighting the importance of human capital in the digital transformation process. Investments in education contribute not only to the formation of digital skills and technological competencies, but also to the effective adoption and utilization of digital infrastructure. The results therefore support the argument that technological development and human capital formation should be viewed as complementary dimensions of long-term development strategies.

The labour force participation rate also displays a positive relationship with digital infrastructure development, although its statistical significance is comparatively weaker. This finding suggests that labour market participation alone may not be sufficient to explain differences in digital infrastructure across countries. Instead, qualitative characteristics of the workforce, including educational attainment, digital skills, and technological adaptability, are likely to play a more important role in shaping digital transformation outcomes.

The diagnostic tests performed within the GMM framework support the validity of the estimated model. The Hansen–Sargan test confirms the appropriateness of the instruments employed, while the Arellano–Bond serial correlation tests indicate the absence of second-order autocorrelation in the differenced residuals. These results provide confidence in the robustness and consistency of the estimated relationships.

From a broader perspective, the findings suggest that digital infrastructure development in Europe is driven by a combination of economic resources, educational investment, and accumulated technological capacity. The strong persistence identified in the model indicates that current disparities in digital infrastructure may continue over time unless supported by targeted and sustained policy interventions. Consequently, reducing digital divides across European countries requires integrated strategies that combine infrastructure investment with policies aimed at strengthening human capital and fostering inclusive economic growth.

The study contributes to existing literature in several ways. First, it adopts a dynamic perspective that explicitly accounts for the persistence of digital infrastructure development. Second, it provides empirical evidence based on a relatively broad sample of European countries, allowing for a comparative

assessment of digital development patterns. Third, it highlights the complementary roles of economic development and education in supporting digital transformation, while emphasizing the importance of considering dynamic effects when analyzing digital infrastructure.

Despite these contributions, the study is subject to several limitations. The relatively short time dimension of the dataset restricts the analysis of long-run structural relationships and limits the possibility of applying alternative econometric approaches. Furthermore, the model does not explicitly incorporate institutional quality, governance indicators, innovation capacity, or measures of digital skills, which may also influence digital infrastructure development. Future research could address these limitations by extending the temporal coverage of the dataset, incorporating additional explanatory variables, and applying alternative dynamic panel estimators such as System GMM. Further investigations could also explore potential nonlinear relationships, threshold effects, and digital convergence processes among European countries.

Overall, the results emphasize that digital infrastructure development is not solely a technological phenomenon, but rather the outcome of broader economic, educational, and structural processes. Understanding these interdependencies is essential for designing effective policies capable of supporting sustainable and inclusive digital transformation across Europe.

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