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Digital Transformation and Economic Sustainability: A comparative analysis of Romania, Poland and Hungary

Dijital Dönüşüm ve Ekonomik Sürdürülebilirlik: Romanya, Polonya ve Macaristan'ın Karşılaştırmalı Analizi

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ABSTRACT

This paper investigates the impact of fixed broadband penetration on labor productivity in three Central and Eastern European countries: Romania, Poland, and Hungary. The accelerated digitization of European economies has become an essential element in national and European development strategies, especially in the context of the transformations imposed by recent crises. This paper analyzes to what extent investments in digital infrastructure – particularly the expansion of high-speed internet networks – contribute to increasing economic efficiency, with a focus on labor productivity. The analysis is based on annual data collected from 2014 to 2023, using simple linear regression models for each country in order to capture national specificities. However, the intensity and consistency of this relationship vary among the three analyzed states, suggesting an important role of the institutional context, the level of digital literacy, and public policies in maximizing the economic benefits of digitalization. The work does not limit itself to highlighting a simple correlation, but also emphasizes the necessary conditions for digitization to generate sustainable long-term effects. In this regard, elements such as the quality of governance, support strategies for SMEs in the process of digital transformation, reducing regional disparities in digital infrastructure, and stimulating innovation through coherent policies are discussed. In conclusion, the study proposes a set of public policy recommendations, focusing on expanding infrastructure in rural areas, developing the digital skills of the workforce, supporting the digital transformation of small and medium-sized enterprises, as well as strengthening the institutional framework. These measures are essential to fully harness the potential of digitalization and to ensure sustainable economic development in the emerging economies of Europe.

Keywords: *Digital transformation, Broadband Penetration, Central and Eastern Europe, ICT Infrastructure, Economic Efficiency*

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ÖZET

Bu makale, Romanya, Polonya ve Macaristan olmak üzere üç Orta ve Doğu Avrupa ülkesinde sabit genişbant penetrasyonunun işgücü verimliliği üzerindeki etkisini incelemektedir. Avrupa ekonomilerinin hızla dijitalleşmesi, özellikle son krizlerin dayattığı dönüşümler bağlamında, ulusal ve Avrupa kalkınma stratejilerinin temel bir unsuru hâline gelmiştir. Bu çalışma, dijital altyapıya yapılan yatırımların – özellikle yüksek hızlı internet ağlarının genişletilmesinin – ekonomik verimliliği ne ölçüde artırdığını, özellikle işgücü verimliliğine odaklanarak analiz etmektedir. Analiz, 2014–2023 dönemine ait yıllık verilere dayanmakta olup, her ülke için ulusal özgünlükleri yansıtmak amacıyla basit doğrusal regresyon modelleri kullanılmıştır. Ancak bu ilişkinin yoğunluğu ve tutarlılığı, analiz edilen üç ülke arasında farklılık göstermektedir; bu da kurumsal bağlamın, dijital okuryazarlık düzeyinin ve kamusal politikaların dijitalleşmenin ekonomik faydalarını maksimize etmedeki önemini vurgulamaktadır. Bu çalışma yalnızca basit bir korelasyonu ortaya koymakla kalmamakta, aynı zamanda dijitalleşmenin uzun vadede sürdürülebilir etkiler yaratması için gerekli koşulları da vurgulamaktadır. Bu bağlamda yönetişim kalitesi, KOBİ'lere yönelik destek stratejileri, dijital altyapıda bölgesel eşitsizliklerin azaltılması ve tutarlı politikalar yoluyla inovasyonun teşvik edilmesi gibi unsurlar ele alınmaktadır. Sonuç olarak, kırsal alanlarda altyapının genişletilmesi, işgücünün dijital becerilerinin geliştirilmesi, küçük ve orta ölçekli işletmelerin dijital dönüşümünün desteklenmesi ve kurumsal çerçevenin güçlendirilmesine odaklanan bir dizi kamu politikası önerilmektedir. Bu önlemler, dijitalleşmenin potansiyelinden tam anlamıyla faydalanmak ve Avrupa'nın gelişmekte olan ekonomilerinde sürdürülebilir ekonomik kalkınmayı sağlamak için hayati öneme sahiptir.

Anahtar Kelimeler: *Dijital Dönüşüm, Genişbant Penetrasyonu, Orta ve Doğu Avrupa, BİT Altyapısı, Ekonomik Verimlilik*

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1. Introduction

In recent years, the discussion among management consultants (Deloitte, 2019; Gartner, 2019; PWC, 2018) and many governments (European Commission, 2020, United Nations, 2020, World Bank, 2020) has centered on how we can accelerate the process of the digital transformation and sustainability. The advancement of automation is increasing both in business and among governments that are planning to exploit them, as noted by Merrill et al. (2019). These new technologies offer huge potential in several areas such as information transparency, coordination, response speed, management, and evaluation (Di Vaio et al., 2021).

It has already been demonstrated that broadband access markedly influences economic efficiency particularly in terms of knowledge diffusion, firm competitiveness, and innovation (Kong and Li, 2022). A notably increasing amount of literature claims that digital transformation is one of the decisive factors in enhancing workforce productivity, particularly in emerging economies (Bocean and Vărzaru, 2023). It has also been proved that investments in broadband infrastructure spur labor market efficiency manifested in reduced unemployment and better job matching (Bhuller et al., 2019).

For emerging economies like Romania, Poland, and Hungary, digitalization is both an opportunity to speed up economic convergence and a strategic challenge. Increasing labor productivity – a key goal for sustainable development – can be boosted by integrating digital technologies.

The evidence suggests that broadband access can foster economic efficiency; however, it crucially depends on a complementary set of factors, including workforce digital skills, regulatory policies, and adoption across different industries (Leagrande et al., 2021). Digital transformation plays therefore an important role in diminishing regional economic imbalances in terms of promoting telework and increasing firm productivity (Škare et al., 2023)

In this context, empirical studies have indicated broadband infrastructure to have a positive and substantial effect on GDP per worker, with proof, from various economies, illustrating how digital connectivity boosts labor efficiency (Atasoy, 2013; Serban et al., 2022). The uptake of broadband services has likewise been associated with higher firm-level productivity, as the case applies to sectors that exploit digital technologies. Furthermore, it was found that the extension of broadband accelerate rural economic development through market access and further agriculture productivity (LoPiccalo, 2021).

However, there is a gap in the empirical literature regarding the direct relationship between broadband internet penetration and labor productivity in Central and Eastern European (CEE) countries. Most studies focus on advanced economies where the level of digitalization is already high. So, there's a need for an analysis that fits the regional context to see how much developing digital infrastructure contributes to economic efficiency in these emerging European economies. The impact of broadband penetration on labor productivity varies from country to country, depending on the economic structure, public policy framework, and the level of digital readiness. For instance, a study on European economies shows that access to high-speed internet boosts productivity, but the effect is significantly stronger in regions with a high level of digital adoption and innovation capacity (Verhoef et al., 2021). Also, the economic efficiency driven by the expansion of broadband internet depends on the regulatory environment and investments in complementary infrastructure (Benseny et al., 2019).

The goal of this paper is to empirically analyze the relationship between fixed broadband internet penetration and labor productivity in Romania, Poland, and Hungary, for the period 2014–2023. The study aims to answer the following research questions:

- Is there a statistically significant relationship between the development of broadband infrastructure and labor productivity growth in the economies analyzed?
- What differences can be observed between the three countries regarding the impact of digitalization on economic efficiency?
- What public policy recommendations can be made regarding investments in digital infrastructure?

To answer these questions, a simple linear regression model will be used, where labor productivity (measured by GDP per capita) will be the dependent variable, and the penetration of fixed broadband internet will represent the independent variable. The analysis will rely on data from sources like the World Bank and Eurostat and it will provide a comparative perspective on the three economies. This research aims not only to fill a gap in the literature but also to formulate evidence-based public policy recommendations in order to leverage the potential of digitalization to support sustainable economic development in Central and Eastern Europe.

Thus, the findings of this research could inform not only academic debates, but also concrete public strategies aimed at bridging the digital divide and fostering inclusive economic growth across Central and Eastern Europe.

2. Theoretical Framework and Literature Review

Sustainability and digitalization are emerging as modern trends that shape the economy and society, consequently having a major impact on different transitions, as mentioned by Del Río Castro et al. (2021). The changes are pragmatic from a social, economic, and even ecological point of view and they lead to a redefinition of the strategic objectives of both nation-states and supranational structures.

One of the most common and widely accepted definitions of “sustainability" was developed by the UN Brundtland Commission in 1987, and it states that “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Gartner, 2019).

Even if the field of “sustainability” is difficult to define, as this term is complex, multidisciplinary, and influences socio-economic organizations at all levels, through actions, decisions, and behaviors, there are still other definitions, such as the one developed by the Chartered Institute of Procurement and Supply (CIPS) which states that it is the act of adopting social, economic, and environmental factors alongside typical price and quality considerations in managing the procurement processes and procedures of organizations.

Not only sustainability needs to be defined, but also “digitalization” and its derivatives, like “digital technology” or “digital transformation”. Although much of the academic literature uses “digitization”, “digitalization”, or “digital transformation” as interchangeable terms (Gong and Ribiere, 2021; Mergel et al., 2019), there are variations in how these terms are defined.

“Digitalization”, in the opinion of Gartner (2021), is the process of transitioning to a digital business as well as the use of digital technologies to create new opportunities for value production, while “digital transformation”, according to Hanelt et al. (2021) is an organizational change driven and influenced by the widespread dissemination of digital technologies. In any case, regardless of the accepted definition, the reality is that digitization is the most important engine of entrepreneurship and innovation.

One of the specific objectives is thus to develop and apply a single-factor linear regression model in order to quantify the relationship between fixed broadband penetration and labor productivity. Complementary to these mechanisms, the endogenous growth theory emphasizes the role of innovation, human capital, and technological

change as internal drivers of productivity (Aghion et al., 1990). The main effect of digital transformation is the structural change of the labor market; therefore, the demand for low-skilled employees decreases, but the demand for employees with IT skills increases. However, this also leads to a re-skilling of candidates applying for various jobs (Picatoste et al., 2021). Although it may initially seem like an imbalance, over time, this is regulated by the labor market. The only real limitation is access to the internet. In this view, broadband infrastructure serves as an enabler for continuous innovation, learning-by-doing, and dynamic firm-level improvements.

The foundation of digital transformation consists of an internet connection that offers high bandwidth and fast data transfer speeds, making data transfer rates faster than ever. Following the expansion of technologies, and also driven by the COVID-19 pandemic which necessitated forced digitalization among many segments of the population, we are talking about online education (Lytras et al., 2025), work from home for many private companies as well as state institutions, communication via Zoom, Teams, or Skype, as well as the evolution of e-commerce even for businesses that had not experienced this before. Essentially, a new commercial model based on digital technologies has emerged, and this model tends to extend even after the pandemic ends, thus becoming increasingly advanced across almost all economic and social areas (Serban et al., 2023).

There are several studies and approaches that have identified a positive relationship between economic performance and digital transformation, thus multiple indicators have been developed to measure the level of digitalization (Myovella et al., 2020; Deloitte, 2020), including composite indices, such as DESI—Digital Economy and Society Index (Olczyk and Kuc-Czarnecka, 2022; Stavytskyy et al., 2019; European Commission, 2020).

Through new technologies that have improved labor productivity, reduced costs, enabled better allocation of personnel, and access to global markets, we can practically talk about digitization as the main vector of growth and economic development. Although other authors (Myovella et al., 2020; Habibi et al., 2020) have demonstrated that digitalization has a direct connection with economic growth, we cannot speak of its universalization at the national level.

This shows that economies with a high level of digitization usually experience significant and consistently positive economic growth. Furthermore, the effects of digital transformation on economic growth vary depending on a country's level of development: in developed countries, the impact is strong, while in low-income economies, it is limited or even negligible. Thus, digitization does not yield the same results everywhere, and its influence varies considerably depending on the economic context (Olczyk et al., 2022).

Numerous empirical studies in high-income countries confirm a strong and statistically significant correlation between broadband diffusion and productivity growth. For instance, Czernich et al. (2011) analyzed 25 OECD countries and found that a 10% increase in broadband penetration was associated with a 0.9–1.5% increase in GDP per capita. Similarly, Atasoy (2013) identified positive labor market outcomes—including lower unemployment and higher wages—in U.S. counties with better broadband access.

Verhoef et al. (2021) argue that the productivity effects of broadband are stronger in countries with higher levels of digital readiness, suggesting that infrastructure alone is insufficient without adequate digital skills, institutional capacity, and firm-level adoption. Detailed studies analyzing the influence of broadband networks on labor productivity in emerging economies remain relatively scarce. Although Bocean and Vărzaru (2023) provide a sustainability-focused perspective on digital transformation in EU member states, the empirical literature dedicated to Central and Eastern European (CEE) countries remains relatively limited. In contrast, other research (for example, Benseny et al. (2019) emphasizes the essential importance of the regulatory framework for the effective implementation and proper use of broadband infrastructure. Leogrande et al. (2021) show that in Eastern Europe, digital disparities remain a challenge, with rural-urban divides and underinvestment in digital infrastructure still present. These disparities hinder the full realization of broadband's potential for economic development, especially in countries like Romania, where broadband infrastructure is unevenly distributed.

Furthermore, the digital transformation paradox may occur: firms invest in digital tools but do not observe immediate productivity gains due to managerial inertia, lack of skills, or resistance to organizational change. This underlines the importance of understanding not just access, but also the effective use of digital infrastructure.

3. Methodology

This paper aims to analyze the relationship between digital transformation and economic development in three Central and Eastern European countries: Romania, Hungary, and Poland. The main objective is to analyze the extent to which the values reflected by the DESI Index (Digital Economy and Society Index) contribute to the growth of GDP per capita. This analysis takes place over a period of ten years, from 2014 to 2023. The data was obtained from the following sources:

- GDP per capita (current USD) – World Bank Open Data (World Development Indicators)

-Digital Economy and Society Index (DESI) – European Commission, Digital Scoreboard

All variables were collected on an annual basis, for each of the three countries, over the period 2014–2023. The variables used in the regression are defined as follows:

- GDPPC: GDP per capita (dependent variable)
- DESI: Digital Economy and Society Index (independent variable)
- C: Constant (intercept term)

$$GDPPC_t = \alpha + \beta \cdot DESI_t + \varepsilon_t$$

Where:

- α is the intercept;
- β is the regression coefficient measuring the marginal impact of DESI on GDP per capita;
- ε_t is the error term;
- GDP_it is the Gross Domestic Product per capita in country i and year t (in current USD);
- DESI_it is the Digital Economy and Society Index score for country i in year t;

Each model is estimated separately for Romania, Poland, and Hungary using Ordinary Least Squares (OLS) with 10 annual observations (2014–2023).

- DESI is an index developed by the European Commission that reflects the dimensions of digital development (connectivity, human capital, internet usage, integration of digital technology, digital public services).
- GDP per capita is a commonly used indicator for economic performance and living standards.
- The simple linear form allows us to isolate the direct relationship between digitization and economic output, without introducing multicollinearity or overfitting risks (especially with only 10 data points per country).

In order to assess how well the model explains the variations in the data, we analyzed the value of the R-squared coefficient, and the significance of the estimated coefficients was tested through t statistics and p values. Before estimation, I reviewed the descriptive statistics and created graphs highlighting the evolution of the DESI indicator

and GDP per capita. The actual estimates were made with the help of EViews 12 software. To capture the particularities of each country, I applied simple linear regression using the ordinary least squares (OLS) method separately for each analyzed state.

4. Results and Discussion

This chapter presents the relationship between fixed broadband penetration and labor productivity, as analyzed using annual data from 2014 to 2023 for Romania, Poland, and Hungary.

Table 1
Evolution of the DESI Index in Romania, Hungary, and Poland (2014–2023)

Year	Romania_DESI	Hungary_DESI	Poland_DESI
2014	33.3	39.7	37.4
2015	35.9	41	39.6
2016	38	42.8	41.2
2017	40.5	44.2	43.3
2018	43.2	46.9	46.1
2019	45.6	48.7	48.5
2020	49.8	52.3	51.1
2021	52.6	55.4	54.8
2022	55.3	58.1	58.6
2023	57.9	60	60.7

Source: Eurostat and European Commission (DESI dataset), author's calculations.

Table 2
Evolution of GDP per capita in Romania, Hungary, and Poland (2014–2023)

Year	Romania_GDP	Hungary_GDP	Poland_GDP
2014	9482	13786	14411
2015	9607	13902	14560
2016	9545	13776	14689
2017	10392	15377	15732
2018	12609	16783	17202
2019	12500	16021	16900
2020	12896	16598	17412
2021	14677	18099	19399
2022	16391	19807	21630
2023	16832	20234	22105

Source: Eurostat and European Commission (DESI dataset), author's calculations.

Separate regression models were estimated for each country using the Ordinary Least Squares (OLS) method. Before presenting the regression results, Table 3 summarizes the descriptive statistics of the two key variables across the three countries.

Table 3
Summary of OLS Regression Results (2015–2022)

Country	Coefficient (β)	Intercept (α)	R^2	p-value	Significance
Romania	319.23	-1939.17	0.947	0	Yes
Poland	342.48	920.66	0.959	0	Yes
Hungary	316.75	946.01	0.938	0	Yes

Source: Compiled by the author based on EViews regressions.

The data show a steady upward trend in both broadband penetration and labor productivity over the period, though at different paces in each country.

Table 4
Regression Output for Romania (2014–2023)

Variable	Coeff.	Std. Err.	t-Stat.	Prob.
C	-1939.174	1228.530	-1.58	0.153
ROMANIA_DESI	319.228	26.755	11.93	0.000
Statistic		**Value**		
R-squared		0.947		
Adjusted R-squared		0.940		
S.E. of regression		679.701		
Sum squared resid		3695984		
Log likelihood		-78.289		
F-statistic		142.364		
Prob(F-statistic)		0.000		
Mean dependent var		12493.1		
S.D. dependent var		2778.231		
Akaike info criterion		16.058		
Schwarz criterion		16.119		
Hannan–Quinn criterion		15.992		
Durbin–Watson stat		1.676		

Source: Author's calculations based on EViews output.

Model: GDP per capita = $\alpha + \beta \times DESI + \varepsilon$
1.Estimated β coefficient: 319.23
2.Intercept (α): -1939.17
3.t-statistic: 11.93 (highly significant, $p < 0.001$)
4.R^2: 0.947
5.F-statistic: 142.36

The results for Romania suggest a strong and statistically significant positive relationship between digitalization (DESI) and GDP per capita. A one-point increase in the DESI index is associated with an estimated $319 increase in GDP per capita. The model explains 94.7% of the variation in GDP per capita, indicating a robust relationship.

Table 5
Regression Output for Poland (2014–2023)

Variable	Coeff.	Std. Err.	t-Stat.	Prob.
C	920.656	1213.241	0.76	0.470
POLAND_DESI	342.476	24.895	13.76	0.000
Statistic		**Value**		
R-squared		0.959		
Adjusted R-squared		0.954		
S.E. of regression		601.854		
Sum squared resid		2,897,822		
Log likelihood		-77.074		
F-statistic		189.242		
Prob(F-statistic)		0.000		
Mean dependent var		17,404.00		
S.D. dependent var		2817.536		
Akaike info criterion		15.815		
Schwarz criterion		15.875		
Hannan–Quinn criterion		15.748		
Durbin–Watson stat		1.296		

Source: Author's calculations based on EViews output.

Model: GDP per capita = $\alpha + \beta \times DESI + \varepsilon$
1.Estimated β coefficient: 342.48
2.Intercept (α): 920.66

3.t-statistic: 13.76 (highly significant, $p < 0.001$)
4.R^2: 0.959
5.F-statistic: 189.24

Poland exhibits the highest R^2 value, suggesting the DESI index accounts for nearly 96% of the variance in GDP per capita. A one-point increase in DESI is associated with a $342 increase in GDP per capita. This indicates an exceptionally strong and significant relationship, highlighting the effectiveness of digital integration in Poland's economy.

Table 6
Regression Output for Hungary (2014–2023)

Variable	Coeff.	Std. Err.	t-Stat.	Prob.
C	946.011	1426.985	0.66	0.526
HUNGARY_DESI	316.751	28.892	10.96	0.000
Statistic		**Value**		
R-squared		0.938		
Adjusted R-squared		0.930		
S.E. of regression		627.724		
Sum squared resid		3,152,550		
Log likelihood		-77.475		
F-statistic		120.193		
Prob(F-statistic)		0.000		
Mean dependent var		16438.30		
S.D. dependent var		2369.097		
Akaike info criterion		15.891		
Schwarz criterion		15.955		
Hannan–Quinn criterion		15.835		
Durbin–Watson stat		1.692		

Source: Author's calculations based on EViews output.

Model: GDP per capita = $\alpha + \beta \times DESI + \varepsilon$
1.Estimated β coefficient: 316.75
2.Intercept (α): 946.01
3.t-statistic: 10.96 (highly significant, $p < 0.001$)
4.R^2: 0.938
5.F-statistic: 120.19

Hungary also shows a strong and statistically significant positive correlation between DESI and GDP per capita. Each additional DESI point increases GDP per capita by approximately $317. Although slightly weaker than Poland, the relationship remains solid, with 93.8% of GDP variation explained by DESI. Structural economic factors or limited broadband use in rural areas may explain this divergence.

5. Conclusions

The results of the regression suggest that broadband penetration has a positive impact on labor productivity in all three analyzed countries, but with slight variations. This means that the intensity and consistency of this effect vary significantly depending on the specifics of each country.

In the case of Poland, our calculations show the strongest connection among the analyzed countries, which could be explained by better digital infrastructure and a stronger integration of ICT tools into the broader economy.

When considering Romania, the situation is not much different but still reflects a moderately strong connection, although significant regional inequalities could weaken the overall result.

Hungary has the weakest correlation, possibly due to the lower adoption of broadband in key economic sectors or insufficient complementary investments, or the country's relatively low level of urbanization.

These findings seem to reflect what other studies have also highlighted - factors such as the digital skill level of the workforce, innovation capabilities in companies, government involvement, investments in digital infrastructure and workforce training, as well as the rural-urban technology gap and internet accessibility, can all influence the extent to which broadband impacts productivity.

6. Policy Recommendations

Based on the results, broadband infrastructure certainly matters for improving economic efficiency in countries like Romania, Hungary, and Poland. However, simply expanding internet access will not be enough. We propose extending broadband in rural areas - these areas are still being left behind, and connecting them could unlock growth where it is most needed, likewise investments in education aimed at improving digital tool usage – not just basic skills, but real and useful training that helps workers adapt in the labor market. Furthermore, helping small and medium-sized enterprises to become digitalized and have qualified personnel – especially those stuck in older, low-productivity sectors - remains fundamentally important. Government strategies are not just digital plans; they must truly work in practice.

Supporting innovation in public administration is again a common issue for this geographical area; public institutions can play a key role in stimulating digitalization if they modernize their own services and adopt efficient digital solutions. The digitalization of administration can indirectly boost the business environment as well as the relationship with citizens and reduce public waste. Another proposal would be programs to reduce the generational gap in digital skills. The elderly and individuals from rural or disadvantaged areas are often excluded from the digitalization process. Therefore, training campaigns tailored to these groups can increase social and economic inclusion.

Also, public-private partnerships for the expansion of digital infrastructure (telecom operators, IT companies) can accelerate the coverage of high-speed internet, especially in poorly connected areas.

There are some limitations to this study as well. First of all, we used only a univariate regression model, so factors such as education (Lytras et al., 2024), investment levels, or governance were not included even though they clearly matter. Secondly, it is difficult to determine with certainty the direction of causality, because we are talking about a complex subject where, besides historical and cultural factors, it is also influenced by the specifics of the analyzed country and its particularities. Additionally, we did not have access to detailed regional or sectoral data, which could have made the analysis more precise. As these countries advance in digitalization, it is essential to understand not only the technology, but also the human and institutional aspects.

Regardless of the circumstances, it is essential to understand at a deeper level that fast internet alone is not enough—it becomes truly effective only when accompanied by inclusive policies and strategic planning.

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