



The Impact of Digital Transformation on Economic Growth: A Panel Analysis of Seven European Countries (2017-2022)

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Abstract

This study examines the impact of digital transformation on GDP growth in seven European countries—France, Italy, Sweden, Germany, Czech Republic, Hungary, and Austria—between 2017 and 2022. Using panel data methods, the analysis highlights the positive contribution of the Digital Economy and Society Index (DESI) and R&D expenditure to economic performance. Tertiary education exhibits a significant negative impact, reflecting inefficiencies in aligning education systems with the demands of a digital economy, while trade openness moderates DESI's impact, with diminishing returns at higher levels. Lagged effects indicate that the benefits of digital transformation take time to materialize. The findings underscore the need for investments in digital infrastructure, innovation, and workforce reskilling, along with addressing regional disparities. This research contributes to understanding digital transformation's role in fostering inclusive and sustainable growth.

Subject Areas

Business & Economic Analysis

Keywords

Digital Transformation, Digital Economy and Society Index, Economic Growth, Panel Data Analysis

1. Introduction

The 21st century is witnessing an unprecedented transformation in economic paradigms, driven by the pervasive influence of digital technologies. Digital transformation, characterized by the integration of innovations such as Artificial Intelligence

(AI), big data, broadband connectivity, and the Internet of Things (IoT), is reshaping how industries operate, businesses compete, and economies grow. It represents more than a technological upgrade; it marks a structural shift in economic systems, altering value chains, introducing novel business models, and accelerating innovation. These changes have positioned digital transformation as a cornerstone of policy agendas, particularly in Europe, where initiatives like the Digital Economy and Society Index (DESI) aim to harness digitalization for equitable growth across member states.

While digital transformation holds immense promise, its uneven adoption highlights stark regional disparities. Countries like Sweden and Germany lead in leveraging digital technologies, while others in Southern and Eastern Europe face challenges related to infrastructure gaps, institutional capacity, and limited investments. The COVID-19 pandemic underscored the criticality of robust digital ecosystems, as nations with advanced digital infrastructure adapted more seamlessly to disruptions, sustaining economic activity through remote work, digital commerce, and online service delivery. Yet, despite these advances, questions remain about how digital transformation directly impacts economic performance and what factors mediate or amplify its effects.

This study delves into the relationship between digital transformation and economic growth, focusing on GDP performance in seven European countries—France, Italy, Sweden, Germany, Czech Republic, Hungary, and Austria—over the period 2017-2022. By employing a panel data approach, the analysis explores how DESI metrics interact with key variables such as Research and Development (R&D) expenditure, education levels, trade openness, and industrial composition. The research addresses critical questions: How does digital transformation contribute to economic growth? Do its benefits materialize immediately, or is there a lagged effect? How do global disruptions, such as the pandemic, influence this relationship?

To answer these questions, the study utilizes Fixed Effects (FEs) and Random Effects (REs) models, incorporating interaction terms to examine how trade openness moderates the impact of digitalization on GDP growth. It also accounts for time-specific shocks through year-fixed effects, enabling an assessment of global events' influence on digital transformation dynamics. The analysis provides a nuanced understanding of the interplay between digital transformation and complementary economic factors, revealing both opportunities and structural inefficiencies.

The findings contribute to the growing literature on digital transformation and its economic implications. They highlight the pivotal roles of DESI and R&D expenditure in driving GDP growth, while uncovering constraints tied to education systems and trade policies. From a policy perspective, the study emphasizes the importance of prioritizing digital infrastructure, fostering digital skills, and aligning educational frameworks with the demands of a digitalized economy. The results also call for forward-looking strategies that address regional disparities and

support long-term investments, ensuring that the benefits of digital transformation are inclusive and sustainable.

This paper is organized as follows: Section 2 reviews the existing literature on digital transformation and economic development. Section 3 outlines the data, model, and methodology employed in the analysis. Section 4 presents the empirical findings, including results from fixed and random effects models, interaction analyses, and temporal trends. Section 5 concludes the study by discussing policy implications and offering recommendations for future research.

2. Literature Review

Digital transformation has fundamentally reshaped economic and societal dynamics, serving as a key driver of productivity, innovation, and competitiveness. It encompasses the adoption of digital technologies—such as Artificial Intelligence (AI), big data analytics, cloud computing, and the Internet of Things (IoT)—in economic activities and governance systems, fostering new business models and efficiencies [1] [2]. As economies increasingly integrate these technologies, the implications for growth, employment, and inequality have become critical areas of research.

One of the most consistent findings in the literature is the role of digital transformation in enhancing productivity. By improving resource allocation and reducing transaction costs, digital technologies drive Total Factor Productivity (TFP), a key determinant of economic growth [3] [4]. Empirical studies indicate that digitally advanced countries experience higher productivity growth, particularly in high-tech and service industries [5]. For instance, the integration of robotics in manufacturing has led to significant cost reductions and quality improvements in countries like Germany and Sweden [6].

The European Union's Digital Economy and Society Index (DESI) provides valuable insights into the link between digital adoption and economic performance. Countries with higher DESI scores, such as Finland and Denmark, report stronger GDP growth compared to lagging nations like Greece and Romania [7]. A study by Niebel [8] found that a 10% increase in broadband penetration leads to a 1.2% rise in GDP per capita, underscoring the importance of connectivity as a foundational element of digital transformation.

Despite its transformative potential, digital transformation exacerbates regional disparities. Advanced economies in Northern and Western Europe leverage robust digital infrastructure and high levels of digital literacy, while Southern and Eastern European nations face challenges such as inadequate ICT investment and skill shortages [9] [10]. For example, rural areas in Bulgaria and Romania exhibit broadband coverage rates far below the EU average, limiting opportunities for digital entrepreneurship [11].

Institutional capacity also plays a crucial role in determining the success of digital transformation. Countries with strong governance and innovation-friendly policies, such as Germany, have successfully implemented initiatives like Industrie

4.0, driving automation and competitiveness in manufacturing [12]. Conversely, bureaucratic inefficiencies in some Eastern European countries hinder the adoption of digital technologies [10].

The labour market effects of digital transformation are complex, presenting both opportunities and challenges. On the positive side, digitalization creates high-skill jobs in fields such as data science, cybersecurity, and AI development, fostering economic resilience and adaptability [13]. The World Economic Forum [14] predicts that 97 million new roles will emerge globally by 2025 due to accelerated digital adoption.

However, automation and digitalization also threaten routine jobs, particularly in manufacturing and administrative roles. In Europe, regions with higher digital adoption tend to exhibit net job creation, while less advanced regions struggle with workforce reallocation [15]. Studies by Autor *et al.* [16] emphasize the importance of reskilling programs and lifelong learning to mitigate these risks and ensure workforce adaptability.

Recognizing the strategic importance of digital transformation, the European Union has implemented various initiatives to accelerate digital adoption. The Digital Single Market (DSM) strategy harmonizes regulations and enhances digital infrastructure, enabling seamless cross-border digital trade and stimulating economic activity [17]. National programs, such as France's Plan France Numérique and the UK's Digital Strategy, aim to foster entrepreneurship and innovation in the digital economy [7].

Education and reskilling are critical components of these efforts. The European Skills Agenda emphasizes lifelong learning and digital literacy to equip workers with essential competencies for a rapidly evolving labor market [15]. For instance, Denmark's "Tech Denmark" initiative focuses on upskilling SMEs to improve competitiveness in global markets [15].

While significant progress has been made in understanding digital transformation, key challenges remain. For instance, the environmental implications of digital technologies, particularly the energy consumption of data centers and blockchain systems, require further investigation [18]. Additionally, the ethical dimensions of AI, including data privacy and algorithmic bias, are gaining attention as critical areas for future research [19].

Another emerging area of interest is the role of digital platforms in reshaping global trade and value chains. Platforms like Amazon and Alibaba dominate e-commerce, raising questions about market concentration and regulatory frameworks [20]. Moreover, non-linear effects of digital transformation on economic growth, including potential diminishing returns at high levels of digital adoption, remain underexplored [8].

This study addresses several gaps in the literature by analyzing the impact of DESI on GDP growth, exploring interaction effects with trade openness, and examining the delayed benefits of digital investments. By focusing on seven European countries, the research contributes to a nuanced understanding of digital transformation's

economic implications in diverse contexts.

3. Data, Model, and Methodology

This study explores the impact of digital transformation on GDP growth across seven European countries—France, Italy, Sweden, Germany, Czech Republic, Hungary, and Austria—over the period 2017-2022. Data were sourced from Eurostat, covering key indicators related to digital transformation, innovation, trade, education, and economic performance. The analysis employs a panel data approach to examine how these factors interact to influence GDP growth.

The primary dependent variable is GDP growth, measured as the annual percentage change in GDP for each country. Independent variables include the Digital Economy and Society Index (DESI), which serves as the main measure of digital transformation. DESI captures dimensions such as connectivity, digital skills, and ICT integration, making it a comprehensive proxy for a country's digital maturity. R&D expenditure, as a percentage of GDP, is included to measure innovation capacity, while tertiary education serves as a proxy for human capital. Trade openness, calculated as the ratio of total trade (exports and imports) to GDP, captures the level of integration into global markets. Finally, industrial share, representing the contribution of industry to GDP, reflects the structural composition of the economy.

The model specification is as follows:

$$\text{GDP Growth}_{it} = \alpha + \beta_1 \text{DESI}_{it} + \beta_2 \text{R\&D}_{it} + \beta_3 \text{Education}_{it} + \gamma_1 \text{TradeOpenness}_{it} + \gamma_2 \text{IndustrialShare}_{it} + \varepsilon_{it}$$

where:

Dependent Variable

GDP Growth_{it} : Annual GDP growth rate for country i at time t .

Independent Variables

DESI_{it} : Digital Economy and Society Index score for country i at time t .

R\&D_{it} : Research and development expenditure as a percentage of GDP for country i at time t .

Education_{it} : Percentage of the population with tertiary education for country i at time t .

Control Variables

$\text{TradeOpenness}_{it}$: Ratio of total trade (exports + imports) to GDP for country i at time t .

$\text{IndustrialShare}_{it}$: Contribution of industry to GDP (percentage) for country i at time t .

4. Empirical Analysis

Panel data methods are employed, estimating Fixed Effects (FEs) and Random Effects (REs) models. Diagnostic tests, robustness checks, and extended analyses (interaction effects, lagged effects, and time effects) provide a comprehensive evaluation.

4.1. Fixed Effects Model

The Fixed Effects (FEs) model was estimated to analyze the relationship between digital transformation and GDP growth, accounting for unobserved heterogeneity across countries. The model explains approximately 70% of the variation in GDP growth within the countries over the observed period, as indicated by the R-squared = 0.7008. The results are summarized in **Table 1**.

Table 1. Fixed effects model results.

Variable	Coefficient (β) (t-test)
DESI	8433.034*** (3.24)
R&D	32.73*** (3.77)
Education	-10906.28 (-1.28)
Trade Openness	2392.82 (1.48)
Industrial Share	-3247.39 (-0.22)
Constant	-174988.4 (-0.32)

The level of significance: ***significant at 1%, **significant at 5%, *significant at 10%.

Key findings include a statistically significant and positive impact of the Digital Economy and Society Index (DESI) on GDP growth ($\beta = 8433.034$, $p = 0.003$), underscoring the role of digital transformation in driving economic performance. Similarly, R&D expenditure ($\beta = 32.73$, $p = 0.001$) significantly contributes to GDP growth, highlighting the importance of investments in innovation.

Interestingly, the coefficient for education ($\beta = -10906.28$) is negative, but it is not statistically significant ($p = 0.210$), suggesting no robust evidence for the impact of tertiary education on economic growth during the study period. Similarly, trade openness ($\beta = 2392.82$, $p = 0.149$) and industrial share ($\beta = -3247.39$) do not show significant effects in the fixed effects model.

The overall F-test ($F(6, 30) = 29.86$, $p = 0.000$) confirms that the fixed effects model fits the data well, with significant variation across countries.

4.2. Random Effects Model

The random effects (RE) model was estimated as an alternative, allowing for time-invariant country-specific effects to be treated as random. The RE model shows strong explanatory power, with an overall R-square = 0.9698. The results are summarized in **Table 2**.

The results reinforce the significance of DESI ($\beta = 10965.04$, $p = 0.000$) and R&D expenditure ($\beta = 27.19$, $p = 0.000$) as key drivers of GDP growth. Unlike the

FE model, education exhibits a significant negative relationship with GDP growth ($\beta = -28304.38$, $p = 0.000$), indicating that tertiary education systems may not be effectively aligned with the skills and competencies demanded by the digital economy. This suggests a misallocation of resources or a lag in adapting curricula to meet market needs. Trade openness remains insignificant ($\beta = 1787.06$, $p = 0.263$), while industrial share displays a significant negative impact ($\beta = -32866.36$, $p = 0.013$).

Table 2. Random effects model results.

Variable	Coefficient (β) (t-test)
DESI	10965.04*** (4.36)
R&D	27.19*** (14.22)
Education	-28304.38*** (-3.99)
Trade Openness	1787.056 (1.12)
Industrial Share	-32866.36** (-2.49)
Constant	1132133** (2.97)

The level of significance: ***significant at 1%, **significant at 5%, *significant at 10%.

The overall $\text{Chi}^2(5) = 311.67$, $p = 0.000$ indicates that the RE model is statistically significant, with a good fit to the data.

4.3. Diagnostics and Model Selection

To determine whether the fixed or random effects model is more appropriate, the Hausman test was conducted. The test statistic ($\text{Chi}^2(5) = 10.87$, $p = 0.0541$) suggests that the null hypothesis (random effects model is consistent and efficient) cannot be rejected at the 5% significance level. Therefore, the random effects model is preferred for this analysis, indicating that unobserved country-specific effects are uncorrelated with the independent variables.

To validate the reliability of the model, several diagnostic tests and robustness checks were performed. Variance Inflation Factors (VIFs) were calculated to assess multicollinearity among the independent variables. The mean VIF was 2.60, with no individual VIF exceeding 4.57, indicating no severe multicollinearity issues. Besides, the Modified Wald test for groupwise heteroskedasticity in the random effects model was used. The null hypothesis of this test assumes homoskedasticity. The test results ($\text{Chi}^2(7) = 38.69$, $p = 0.08$) indicate that we fail to reject the null hypothesis, suggesting no strong evidence of heteroskedasticity across the groups. Serial

correlation was assessed using Wooldridge's test for autocorrelation in panel data. The null hypothesis of the test assumes no first-order autocorrelation. The test yielded a p-value higher than 0.05, indicating that we fail to reject the null hypothesis. This result suggests no evidence of serial correlation in the panel data, supporting the reliability of the regression estimates. However, for robustness, re-estimating the models with clustered standard errors at the country level confirms the significance of DESI and R&D, while education remains negative but insignificant in the FE model.

4.4. Interaction Effects: Trade Openness and DESI

To assess how trade openness influences the relationship between digital transformation (as measured by DESI) and GDP growth, an interaction term (DESI \times Trade Openness) was incorporated into the random effects model. This term captures whether higher levels of trade openness amplify or diminish the benefits of digital transformation. The results, detailed in **Table 3**, provide important insights into how these factors interplay, highlighting the complex dynamics.

Table 3. Random effects model with interaction effects.

Variable	Coefficient (β) (t-test)
DESI	23739.69*** (4.64)
R&D	32.88*** (4.38)
Education	-956.42 (-0.12)
Trade Openness	12081.75*** (3.75)
Industrial Share	-24478.84* (-1.75)
DESI \times Trade	-186.71*** (-3.34)
Constant	-861040.1 (-1.67)

The level of significance: ***significant at 1%, **significant at 5%, *significant at 10%.

Key findings reveal that DESI has a robust and statistically significant positive effect on GDP growth ($\beta = 23739.69$, $p = 0.000$), confirming that digital transformation is a critical driver of economic performance. Trade openness also independently contributes positively to GDP growth ($\beta = 12081.75$, $p = 0.001$), underscoring its role in integrating economies into global markets. However, the negative and significant interaction term (DESI \times Trade Openness: $\beta = -186.71$, $p = 0.002$) points to diminishing returns on DESI's contribution to growth at higher levels of trade openness. This suggests that as economies become more trade-

reliant, the marginal gains from digital transformation are constrained, potentially due to factors such as overdependence on external digital infrastructure, competition from foreign digital services, or saturation effects in trade-dominant industries.

These findings underscore the need for a balanced approach to digital transformation and trade policies. Policymakers should ensure that DESI-driven growth is not undermined by excessive trade reliance, which could reduce incentives for domestic digital innovation or create dependencies on foreign digital ecosystems. For instance, countries heavily reliant on importing digital technologies may face challenges in fostering local digital industries. Additionally, trade-dominant sectors such as manufacturing might experience slower integration of advanced digital tools, limiting the overall economic impact. Addressing these dynamics requires tailored policies that encourage domestic innovation while leveraging trade to complement digital transformation. Future research should delve into specific mechanisms, such as the role of global digital platforms, trade diversification, and sectoral disparities in digital adoption.

4.5. Lagged Effects of Digital Transformation

To support the hypothesis that digital transformation (measured by DESI) has positive effects on GDP growth, a one-period lagged DESI variable was introduced into the random effect model. This analysis allows us to determine whether the impact of digital transformation on economic performance materializes with a delay. The results are presented in **Table 4**.

Table 4. Random effects model with lagged DESI.

Variable	Coefficient (β) (t-test)
Lagged DESI	12782.22*** (2.94)
R&D	30.93** (2.68)
Education	-18412.91 (-1.31)
Trade Openness	2702.53 (1.54)
Industrial Share	-7411.78 (-0.40)
Constant	27319.35

The level of significance: ***significant at 1%, **significant at 5%, *significant at 10%.

Key findings reveal that the lagged DESI variable has a statistically significant positive effect on GDP growth ($\beta = 12782.22$, $p = 0.007$), suggesting that the economic benefits of digital transformation take time to manifest. This result underscores the importance of viewing digital transformation investments as long-term

strategies rather than immediate catalysts for economic growth. Policymakers should consider the delayed nature of these benefits when designing and evaluating digital transformation initiatives.

R&D expenditure ($\beta = 30.93$, $p = 0.013$) remains a significant driver of GDP growth, emphasizing the continued importance of innovation in economic performance. However, other variables, including education, trade openness, and industrial share, are not statistically significant in this model.

The overall F-test ($F(6, 23) = 19.54$, $p = 0.0000$) confirms that the model fits the data well, with significant variation across countries. The results highlight the necessity of sustaining digital transformation policies over time to realize their full economic potential. Future research could explore additional lags to identify whether these effects persist beyond one period or if the impact diminishes over time.

4.6. Time Effects: Year Fixed Effects

To account for potential global shocks or temporal trends, year-fixed effects were included in the random effects model. This adjustment helps isolate the impact of digital transformation (measured by DESI) and other variables on GDP growth by controlling for time-specific factors such as economic crises or global policy changes. The results are presented in **Table 5**.

Table 5. Random effects model with year-fixed effects.

Variable	Coefficient (β) (t-test)
DESI	45633.24*** (2.28)
R&D	38.14*** (3.77)
Education	-19.87695 (-0.00)
Trade Openness	-396.9094 (-0.14)
Industrial Share	-14275.47 (-0.97)
Year: 2018	-120914.9** (-2.19)
Year: 2019	-269421.2** (-2.58)
Year: 2020	-407122.6** (-2.54)
Year: 2021	-556221.9** (-2.42)
Year: 2022	-723562** (-2.27)
Constant	-1385028* (-1.73)

The level of significance: ***significant at 1%, **significant at 5%, *significant at 10%.

Key findings reveal that DESI ($\beta = 45633.24$, $p = 0.009$) and R&D ($\beta = 38.14$, $p = 0.001$) remain significant and positively associated with GDP growth, reinforcing the critical role of digital transformation and innovation in economic performance.

The inclusion of year-fixed effects also highlights significant negative coefficients for all year dummy variables (2018-2022). These results suggest that GDP growth in the observed countries experienced notable declines during this period, likely reflecting global economic disruptions such as the COVID-19 pandemic and other macroeconomic challenges. For example, the year 2020, corresponding to the height of the pandemic, shows a significant negative impact ($\beta = -407122.6$, $p = 0.018$).

Education, trade openness, and industrial share remain statistically insignificant in this model, indicating that their direct effects on GDP growth are minimal when time effects are accounted for.

The overall F-test ($F(10, 25) = 8.31$, $p = 0.0000F$) confirms the joint significance of the model, and the $\rho = 0.992$ indicates that most of the variance is explained by unobserved country-specific effects. These findings underscore the importance of controlling for temporal factors in panel data analyses, particularly during periods of global economic volatility.

5. Conclusions

This study has explored the relationship between digital transformation and GDP growth in seven European countries—France, Italy, Sweden, Germany, Czech Republic, Hungary, and Austria—over the period 2017-2022, addressing the critical question of how digitalization contributes to economic performance. By employing panel data methods, including fixed effects and random effects models, and conducting advanced analyses, the research provides a comprehensive understanding of the economic impacts of digital transformation as measured by the Digital Economy and Society Index (DESI).

The findings underscore the pivotal role of digital transformation in driving GDP growth. The positive and significant influence of DESI across all model specifications highlights the importance of widespread broadband connectivity, digital skills, and ICT integration in fostering economic progress. Investments in Research and Development (R&D) also emerge as a critical determinant, further emphasizing the role of innovation in enabling sustainable growth. These results confirm the transformative potential of digital technologies in enhancing economic resilience and competitiveness.

However, the study reveals nuanced challenges in the relationship between education and economic performance. The mixed findings regarding tertiary education suggest inefficiencies in aligning higher education systems with the skills required for a digital economy. This disconnect underscores the urgent need for reforms to ensure that human capital development translates into tangible economic benefits. Additionally, interaction analyses indicate that while trade openness complements

digital transformation, diminishing marginal returns may arise at higher levels of trade, calling for a balanced approach to trade and digital policies.

The research further highlights the delayed nature of economic benefits associated with digital transformation. Lagged DESI variables reveal that the impact of digitalization materializes over time, requiring policymakers to adopt a long-term perspective in evaluating digital initiatives. Year-specific analyses demonstrate the profound effects of global economic shocks, such as the COVID-19 pandemic, which negatively impacted GDP growth. Nevertheless, countries with robust digital infrastructures were better positioned to mitigate these disruptions, illustrating the resilience offered by digital preparedness.

These findings carry significant implications for policymakers. Investments in digital infrastructure must remain a priority for European governments, with a focus on enhancing broadband access, fostering digital literacy, and integrating ICT into key sectors. R&D funding should be sustained and directed toward innovative technologies such as artificial intelligence and big data, which have the potential to amplify the benefits of digital transformation. Education systems require targeted reforms to address structural inefficiencies, particularly the observed negative impact of tertiary education on economic growth. Policymakers should prioritize aligning curricula with market needs, enhancing digital literacy, and expanding access to practical, technology-focused programs to ensure graduates can contribute effectively to digitally driven economic sectors. This calls for collaboration among governments, academic institutions, and industries to bridge the gap between education and the labor market.

Moreover, the interaction effects identified in the study suggest that trade policies should complement digital strategies to optimize economic outcomes. Policymakers must carefully calibrate trade openness while addressing structural constraints that limit productivity gains from digital adoption. Finally, the delayed impacts of digital transformation reinforce the need for patient, sustained investments and evaluation frameworks that consider long-term outcomes.

While this study provides valuable insights into the economic implications of digital transformation, it also opens avenues for further research. Expanding the dataset to include a broader range of countries and longer timeframes would enhance the generalizability of these findings. Additionally, future research could investigate the non-linear effects of digital transformation, exploring whether diminishing returns occur at advanced levels of digital adoption. Examining the interplay between digitalization and social outcomes, such as employment, income inequality, and regional disparities, would provide a more holistic perspective on its societal impact.

As digital technologies continue to evolve, future studies should focus on the implications of emerging innovations, including blockchain, quantum computing, and advanced robotics, on economic growth. Policymakers must remain agile and forward-thinking to adapt to the rapidly changing digital landscape, ensuring that the benefits of digital transformation are inclusive, equitable, and sustainable over the long term.

Conflicts of Interest

The authors declare no conflicts of interest.

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