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Institutions, digital investment potential and productivity growth in EU and Southeast Asia

Andrej Privara and Anetta Caplanova
Faculty of Economics and Finance,
Bratislava University of Economics and Business, Bratislava, Slovakia

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Abstract

Purpose – This paper investigates how digitalisation – encompassing broadband infrastructure (basic connectivity), ICT investment (usage intensity) and e-commerce – impacts productivity growth in European Union and Southeast Asian economies. It also explores whether robust institutional quality magnifies digital returns.

Design/methodology/approach – A panel of 38 countries (2012–2023) was compiled using World Bank, Eurostat and ITU data. System GMM regressions address endogeneity and dynamic effects. Growth accounting methods, including Data Envelopment Analysis and the Malmquist Index, validate the regression findings and gauge efficiency and technological shifts.

Findings – The findings highlight that investing in ICT and using e-commerce strongly boost productivity, while broadband connectivity alone has limited impact unless supported by good governance. High-quality institutions enhance the effectiveness of digital investments. Moreover, greater digitalisation reduces unemployment and encourages wider workforce participation, demonstrating significant economic and social benefits.

Research limitations/implications – Secondary macro data may obscure regional nuances. Future studies could use firm-level datasets or investigate emerging digital tools (e.g. AI).

Practical implications – Policymakers should combine investment in digital connectivity with efforts to strengthen institutions and improve digital skills to achieve sustained economic growth.

Social implications – Bolstering inclusive digital adoption can reduce regional inequalities, promote economic resilience and lay groundwork for broader sustainable development.

Originality/value – Unlike previous studies that mainly focus on digital infrastructure, this research uniquely shows how the intensity of digital use and the quality of institutions jointly drive productivity. Integrating institutional theory with practical economic analysis across two diverse regions, it offers fresh insights into achieving meaningful productivity gains from digitalisation.

Keywords Digitalisation, Productivity growth, Institutional theory, ICT investment

Paper type Research article

1. Introduction

The rapid advancement of digital technologies has significantly influenced economic development across the globe. Digitalisation has emerged as a pivotal driver of productivity growth, offering businesses innovative tools to enhance efficiency, streamline processes, and expand market reach. Numerous studies have explored the relationship between digital transformation and economic performance, highlighting the role of digital adoption in promoting growth and innovation (Hawash and Lang, 2020; Liu *et al.*, 2022; Zhang *et al.*, 2022). The digital economy has been recognised as a fundamental component in fostering competitive advantages for firms and economies alike (Tran and Nguyen, 2022; Kim, 2019). Research has also established that investments in information and communication technology (ICT) are closely linked to improvements in labour productivity and reductions in

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unemployment rates (Du and Wang, 2024; Deng *et al.*, 2024; Adel and Naili, 2024). Despite these insights, digitalisation's impact on productivity has not been uniform, with significant disparities observed between regions such as the EU and Southeast Asia. This uneven impact is partly due to variations in how effectively countries can leverage digital technologies, influenced substantially by the quality of their institutional frameworks, such as governance, policy stability, and regulatory effectiveness. As digital transformation continues to reshape economic landscapes, understanding the causes and consequences of these differences has become crucial.

While there is a growing body of literature examining the relationship between digitalisation and economic performance, gaps remain in understanding the distinct mechanisms driving regional disparities (Teruel *et al.*, 2024; Mirza *et al.*, 2024; Hasnaoui, 2025). Existing research highlights the role of digital infrastructure, institutional quality, and market structures in influencing productivity outcomes (Polozova *et al.*, 2021; Hakam *et al.*, 2023; Kolupaieva *et al.*, 2024). However, there is limited empirical evidence examining how these factors interact and how they differentially impact productivity growth across EU and Southeast Asian economies. Previous studies have often overlooked the role of digital gap convergence and the dynamic interplay between ICT variables and macroeconomic conditions (Török, 2024; Tarjáni *et al.*, 2023). This paper specifically addresses this gap by exploring how institutional quality conditions the relationship between digitalisation and productivity.

The selection of 27 EU countries and 11 Southeast Asian economies between 2012 and 2023 was strategically motivated by significant digital-policy developments and reforms. During this period, major initiatives—such as the EU's Digital Agenda, the Digital Single Market strategy, and Southeast Asia's ASEAN Digital Masterplan 2025—substantially reshaped digital infrastructures, regulatory landscapes, and technology adoption patterns. These reforms, combined with accelerated technological advancements, offer a critical window to assess the effects of digital investments in varied institutional environments.

Exploring the factors that contribute to digital disparities is critical for policymakers (Wang and Zhan, 2025), business leaders, and development agencies seeking to reduce inequalities and enhance economic outcomes. Investigating the determinants of digital differences and their influence on productivity offers actionable insights for improving digital adoption strategies and optimizing ICT investments (usage intensity). This study will also provide practical recommendations to address challenges faced by businesses in regions where digital transformation has lagged. Beyond immediate applications, this research advances discussions on the convergence of digital development across economies and the implications for future economic integration (Yu, 2024; Herrador, 2023; Alqaralleh, 2024).

This study contributes to institutional theory by examining how digital infrastructure, regulatory environments, and market conditions influence productivity outcomes. Integrating insights from growth accounting methods and dynamic panel regression analysis allows this research to extend theoretical frameworks exploring the relationship between digitalisation and economic growth (Urbano *et al.*, 2024). The study's findings will provide fresh insights into the role of digital disparities in shaping broader economic dynamics, refining existing theoretical perspectives and offering a more comprehensive understanding of digital convergence trends.

This paper builds on prior research by incorporating a diverse range of economic indicators and digitalisation variables to evaluate their combined effect on productivity. The application of growth accounting techniques such as DEA and the Malmquist Index introduces new empirical insights into the relationship between digital gaps and productivity growth (Lyu *et al.*, 2024). The study employs advanced dynamic panel models, including the GMM (Arellano-Bond) and Blundell-Bond estimators, to address endogeneity concerns and better capture temporal effects (Hawash and Lang, 2020; Metawa *et al.*, 2024; Mohnot *et al.*, 2024). Exploring ICT variables in interaction with institutional and market conditions adds depth to the existing literature on digitalisation and economic development (Mondekar, 2017; Nasraoui *et al.*, 2024; Eling, 2024).

This research not only contributes to academic discourse but also holds practical implications for policymakers and industry professionals. The findings will provide actionable insights for improving digital adoption strategies, enhancing ICT investments (usage intensity), and fostering inclusive economic growth. The study also identifies key factors that may guide the development of tailored policy frameworks to address digital inequalities. Future research can expand on these insights by exploring sector-specific impacts of digitalisation or examining country-level variations in digital adoption outcomes. Addressing these broader concerns will help inform strategies that promote sustainable growth and economic resilience across diverse regions.

2. Literature review

Understanding the impact of digitalisation on productivity growth requires more than identifying technological advances—it demands a closer look at the institutional frameworks that shape their outcomes. Over recent decades, rapid digital transformations have redefined production models, labour markets, and global value chains. However, the economic benefits of digitalisation remain unevenly distributed across regions, raising questions about the underlying mechanisms responsible for these disparities. While digital infrastructure and ICT investment (usage intensity) are essential, they do not operate in a vacuum. The way institutions govern and support these investments plays a crucial role in determining whether digitalisation translates into sustainable productivity gains. Yet, existing research typically addresses technological infrastructure and institutional quality separately, rarely providing integrated frameworks to clarify how institutions moderate digital impacts effectively (Urbano *et al.*, 2024; Polozova *et al.*, 2021). This limited integration leaves important questions unanswered regarding the specific conditions under which digital investments yield productivity benefits.

Historically, productivity growth has been linked to waves of technological innovation—from mechanisation to electrification to automation. With the advent of the digital economy, scholars have debated whether digitalisation marks a comparable revolution or whether its impact has been overstated (Anderton and Reimers, 2020; Evangelista *et al.*, 2014; Bai *et al.*, 2023; Dobrovič and Koraus, 2015). Early studies highlighted the potential of ICTs to accelerate economic growth and reduce inefficiencies. However, as digital technologies diffused globally, evidence of a consistent productivity payoff remained mixed. Some countries reaped measurable gains, while others saw limited improvements or widening inequality. These outcomes prompted a shift in research focus, away from technologies themselves and toward the enabling environments in which they are embedded.

In today's policy and academic circles, the conversation has matured. Attention has turned toward digital inclusivity, institutional quality, and governance as critical factors moderating the digital-productivity link (Urbano *et al.*, 2024; Polozova *et al.*, 2021; López-Felices *et al.*, 2023; Koraus *et al.*, 2015; Břečka and Koraus, 2016). Southeast Asian countries, for example, continue to experience fragmented digital development, despite significant investment in infrastructure (Yu, 2024; Mondekar, 2017). At the same time, EU economies face internal gaps between core and peripheral regions, challenging assumptions of uniform digital maturity (Kolupaieva *et al.*, 2024; Tarjáni *et al.*, 2023). Emerging scholarship suggests that institutional environments—such as legal transparency, policy consistency, and administrative efficiency—directly shape the productivity outcomes of digitalisation (Du and Wang, 2024; Liu *et al.*, 2022). Besides, contemporary literature increasingly recognises the digital gap as a measurable construct influencing economic convergence (Török, 2024; Herrador, 2023), yet few studies integrate this construct into empirical models capturing cross-regional productivity trends.

Recent literature on digitalisation in developing economies further highlights the importance of informal institutions and social capital as critical yet often overlooked factors influencing digital adoption and effectiveness (Lyu *et al.*, 2024; Duong, 2023). Informal

networks, trust-based interactions, and localised norms often significantly affect how digital technologies are utilised, especially in regions with weak formal institutions. However, empirical research explicitly incorporating these informal institutional dimensions into models of digital productivity remains scarce, indicating a significant knowledge gap.

Despite growing evidence on the interplay between institutions and digitalisation, there remains a critical gap in theory and method. Most empirical work focuses either on institutional quality or digital variables in isolation, failing to explore how these dimensions interact. This creates ambiguity about the exact mechanisms through which institutional quality enhances or inhibits the productive use of digital technologies. This study responds to this omission by applying institutional theory to investigate how regulatory environments, governance structures, and digital infrastructure collectively influence productivity growth. It draws upon recent empirical findings that argue for the moderating role of institutions in unlocking the value of digital tools (Lyu *et al.*, 2024; Kim, 2019; Duong, 2023; Gombár *et al.*, 2022; Koraus *et al.*, 2019). Besides, unlike prior work that treats digitalisation as a linear input into productivity models, this study adopts a dynamic panel approach to examine how convergence in digital capacity—what we call "digital gap narrowing"—affects lagging regions over time. In doing so, it introduces a more nuanced conceptualisation of productivity growth, one that captures both structural conditions and institutional capacity as interdependent variables (Cobbinah *et al.*, 2025; Aly, 2022).

The significance of this research lies in its ability to inform digital development strategies that are sensitive to both technological and institutional realities. Specifically, this study clarifies precisely how the interplay between formal institutional quality and digital investment intensity shapes productivity outcomes, thereby filling the critical gap regarding integrated empirical assessments across developed and developing contexts. While high-income economies may assume that digital investment alone guarantees productivity gains, this study highlights that without institutional scaffolding, such investments may underperform or even exacerbate existing inequalities (Kunkel and Tyfield, 2021; Sun *et al.*, 2025). Targeting both EU and Southeast Asian regions, this research not only captures variation in digital maturity but also generates policy-relevant insights for governments and development agencies operating in diverse contexts. The findings promise to contribute to a more grounded understanding of how digital convergence can drive inclusive growth when coupled with institutional support, ultimately enabling more effective design and implementation of ICT and regulatory policies (Zhao *et al.*, 2025; Qian *et al.*, 2024).

2.1 Theoretical framework

This study adopts institutional theory as its central analytical lens to investigate how digitalisation shapes productivity growth across regions with varying levels of institutional maturity. Institutional theory emphasises the pivotal role of social, political, and economic structures in influencing economic outcomes. Institutions are not merely background conditions—they actively shape the rules of the game by defining the regulatory frameworks, norms, and informal constraints that guide business behaviour, investment decisions, and technological innovation (Diaz Tautiva *et al.*, 2023; Le *et al.*, 2023; Urbano *et al.*, 2024). In the digital age, the interaction between institutions and technology becomes increasingly critical, as institutional conditions determine the speed, scope, and sustainability of digital adoption.

At its core, institutional theory posits that differences in governance, policy implementation, and regulatory integrity directly affect a nation's capacity to absorb and leverage technological change. Countries with transparent legal systems, accountable public institutions, and coherent digital strategies are more likely to create environments conducive to ICT diffusion and productivity-enhancing innovation. These institutional attributes influence how public and private actors respond to emerging digital tools, shaping both the quality of infrastructure and the efficiency of its use. As Du and Wang (2024) explain, digital infrastructure without institutional readiness often results in underutilisation and fragmented

development. In contrast, robust institutions facilitate coordination, build trust, and lower transaction costs—conditions essential for realising the productivity gains associated with digitalisation.

Institutional quality also plays a moderating role in managing digital disparities. Weak institutions may exacerbate digital divides, particularly in regions with low administrative capacity or inconsistent policy implementation (Polozova *et al.*, 2021). For example, Kolupaieva *et al.* (2024) argue that even when financial investments in ICT are substantial, the absence of strong institutional scaffolding can lead to inefficiencies, corruption, and regulatory fragmentation—undermining the potential impact on productivity. In contrast, economies with effective governance systems can channel digital investments into tangible performance outcomes, from increased labour productivity to enhanced environmental performance (Deng *et al.*, 2024; Liu *et al.*, 2022).

This study builds upon and extends institutional theory by integrating it with empirical evidence on digital gap convergence, broadband deployment, and ICT capital intensity. Prior research has treated digitalisation largely as a technological phenomenon, often ignoring the institutional environments in which it operates. Highlighting the institutional context as a determining factor of digital impact, this framework recognises that productivity gains are not guaranteed by digital investment alone. They emerge from the alignment between technological opportunities and institutional capacity to harness them effectively (Cobbinah *et al.*, 2025; Aly, 2022).

2.1.1 The Solow Paradox and its relevance to digitalisation. In response to the Solow Paradox, which suggests that despite significant investments in digital technologies, productivity gains have been elusive, this study examines how institutional quality and usage-based digital investments (such as e-commerce and ICT capital) mediate the relationship between basic connectivity (broadband) and productivity. While previous research has focused on the role of digital infrastructure alone, we argue that institutional conditions are crucial in unlocking the potential productivity gains from digital investments. Our empirical approach tests whether regions with strong governance frameworks see more substantial returns on digital investments, thus addressing the Solow Paradox by considering institutional factors as mediators of the digital-productivity link.

The Solow Paradox (Solow, 1999) highlighted that while substantial investments in information technology were made, they did not lead to proportional increases in productivity. This paradox has persisted over time, questioning the direct impact of digital infrastructure on economic growth. Our study builds on this by integrating Blundell and Bond (1998) dynamic panel data methodology and testing whether institutional quality and digital investments mediate the expected productivity outcomes. The empirical analysis further expands on Cobbinah *et al.* (2025) by suggesting that institutional quality can serve as a critical intermediary, ensuring that digital investments are harnessed effectively to generate productivity gains.

Also, this perspective allows the study to move beyond simplistic dichotomies of developed versus developing regions. It acknowledges that even within high-income economies, institutional quality can vary significantly affecting how digital tools translate into productivity outcomes (Heyman *et al.*, 2021; Kim, 2019). As such, institutional theory provides a more nuanced and adaptable lens through which to assess regional differences in digital transformation and their broader economic consequences.

2.2 Hypotheses development

The impact of digitalization on productivity is not solely determined by the level of technological infrastructure but is significantly shaped by the quality of institutions in place. Each digitalization component—broadband infrastructure (basic connectivity), ICT investments (usage intensity), and e-commerce adoption (usage intensity)—interacts with institutional quality, influencing how effectively these technologies can drive productivity

gains. Strong institutions, characterized by transparent governance, effective regulations, and policy coherence, enhance the productivity potential of digital investments. In contrast, weaker institutions often hinder the optimal use of these technologies, resulting in suboptimal outcomes. Therefore, the success of digitalization shown in Figure 1, in boosting productivity depends not only on the presence of digital tools but also on the strength of the institutional environment supporting their deployment.

As show in Figure 1, broadband connectivity has become a foundational component of modern economies, functioning as a core enabler of digital transformation and economic productivity. It facilitates access to digital platforms, supports data-intensive operations, and unlocks new modes of value creation. In practical terms, broadband access allows firms to adopt cloud computing solutions, develop e-commerce capabilities, and enable flexible work environments through remote collaboration. Countries with more extensive broadband infrastructure (basic connectivity) consistently demonstrate higher levels of productivity, not simply because of access, but because connectivity enables faster information flows, more efficient supply chains, and expanded consumer engagement (Du and Wang, 2024; Liu *et al.*, 2022). In addition to improving firm-level performance, broadband access enhances regional competitiveness by enabling the diffusion of innovation across sectors and geographies (Cinquegrana *et al.*, 2024). The positive association between broadband penetration (basic connectivity) and productivity has been well-documented across both developed and developing contexts, including within fragmented regions such as Southeast Asia and the EU (Hawash and Lang, 2020; Tran and Nguyen, 2022). As a result, this study posits the following hypothesis:

H1. Higher broadband penetration (basic connectivity) rates positively influence productivity growth in both EU and Southeast Asian economies.

Investments in information and communication technology (ICT) infrastructure form the technological backbone of digital transformation. Such investments equip firms with tools for automating processes, enhancing decision-making, improving data management, and elevating customer engagement. However, the productivity returns of ICT investment (usage intensity) are not uniform—they are significantly conditioned by the regulatory and institutional environment in which they are deployed (Lyu *et al.*, 2024; Aly, 2022). Research has shown that ICT investment (usage intensity) produces stronger productivity gains when paired with well-functioning institutions that facilitate technology absorption and ensure efficient resource allocation (Cobbinah *et al.*, 2025; Kolupaieva *et al.*, 2024). In digitally advanced settings, ICT capital deepening amplifies innovation capacity and reduces operational frictions, while in less regulated environments, its impact is often diluted. Therefore, this study proposes:

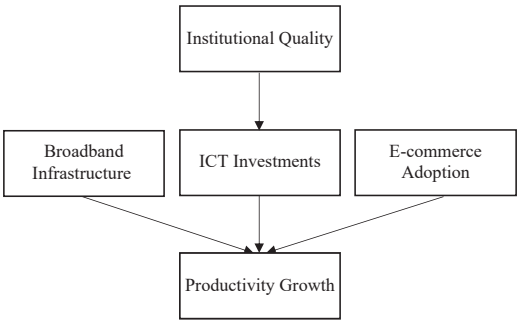

Figure 1. Conceptual framework interaction between digitalization components and institutional quality, Source: Created by authors

H2. Increased ICT investment (usage intensity) leads to greater productivity growth across economies with developed digital infrastructure.

Institutional quality is a critical determinant of how effectively digital technologies are implemented and scaled. Nations with transparent legal systems, coherent policies, and reliable governance structures offer the stability needed for businesses to undertake digital transitions. Strong institutions reduce uncertainty, enable long-term investment planning, and promote innovation ecosystems. They also help mitigate risks related to data privacy, cybersecurity, and interoperability—factors that are essential for the smooth functioning of digital markets (Urbano *et al.*, 2024; Polozova *et al.*, 2021). Besides, institutions facilitate collaborative innovation and knowledge transfer by reducing transaction costs and establishing clear rules of engagement. This moderating effect implies that digitalisation on its own is not sufficient: it must be embedded within institutional architectures that support its productive deployment (Sun *et al.*, 2025; Kim, 2019). Hence, we hypothesise:

H3. Institutional quality positively moderates the relationship between digital adoption and productivity growth.

Beyond the effects of digital investment and institutional conditions, this study explores the role of digital convergence—the process through which regions with lower digital maturity catch up with digitally advanced economies. As developing regions expand broadband access, invest in ICT capital, and upskill their workforce, they begin to close the digital gap. This convergence yields measurable productivity improvements through mechanisms such as knowledge spillovers, increased participation in global value chains, and the replication of successful digital strategies (Yu, 2024; Herrador, 2023). Several studies have argued that the narrowing of digital divides can act as a catalyst for broader economic convergence, particularly when supported by targeted policy frameworks (Qian *et al.*, 2024; Wibowo *et al.*, 2025). To capture this dimension, the study introduces the following hypothesis:

H4. Digital gap convergence will accelerate productivity growth in lagging regions.

Together, these hypotheses provide a multidimensional lens through which to examine the complex relationship between digitalisation and productivity growth. They enable this study to move beyond linear models of technological diffusion by accounting for both institutional moderation and regional convergence. This framework supports a richer empirical investigation that can inform policy measures aimed at fostering inclusive digital development across the European Union and Southeast Asia.

3. Methodology

3.1 Research design and sample

This study employs a panel-based quantitative research design using macroeconomic secondary data to examine the interplay between digitalisation and institutional quality in affecting productivity growth in EU and Southeast Asian economies. The use of secondary data is justified by its capacity to generate standardized and internationally comparable indicators over an extended period, thereby reducing biases commonly encountered with self-reported or perception-based surveys (Du and Wang, 2024; Kolupaieva *et al.*, 2024). Specifically, each variable's source is meticulously documented: broadband indicators and e-commerce measures are sourced from ITU and Eurostat/ASEANStats respectively; GDP and related economic indicators are drawn from the World Bank's WDI and the Penn World Table; and governance indicators are obtained from the Worldwide Governance Indicators (WGI).

The sample includes all 27 EU countries and 11 Southeast Asian economies, spanning from 2012 to 2023—a period capturing major policy shifts, digital expansions, and institutional reforms. Specifically, the EU's Digital Single Market Strategy (2015), the ASEAN ICT

Masterplan (2015, 2025), and numerous national-level reforms provide a robust basis for examining digital productivity linkages over this timeframe. The exclusion of some countries due to incomplete or inconsistent data potentially limits the generalizability of the findings, particularly in representing the nuances of smaller or less digitally mature economies. The final unbalanced panel comprises 456 observations, ensuring sufficient cross-sectional and time variation for robust econometric analysis (Kim, 2019).

Data cleaning was conducted in several stages:

(1) Initial screening involved outlier detection using interquartile range (IQR) thresholds and visual inspection of time series plots to identify anomalous values.

(2) Inconsistencies and missing observations were addressed through linear interpolation for gaps of up to two years, with a detailed record maintained for each modified observation.

(3) Merging procedures across multiple databases were rigorously standardized by aligning reporting periods and variable definitions, with cross-validation checks to reconcile discrepancies between sources.

To account for potential biases due to differing data collection methods and reporting frequencies, we compared metadata from World Bank, Eurostat, ITU, and other sources. Adjustments—such as re-scaling or temporal alignment—were applied where necessary to ensure the data's comparability and to minimize measurement errors.

Dataset limitations, such as regional differences in data collection methodologies and reporting frequencies, were systematically addressed through re-scaling, temporal alignment, and validation against multiple data sources. Nonetheless, these inherent limitations could still bias results, particularly in cross-regional comparisons.

3.2 Variables and measurements

3.2.1 Dependent variable. Labour Productivity Growth is measured as the annual percentage change in real GDP per person employed—a standard indicator for assessing efficiency in labour utilization (Cinquegrana *et al.*, 2024). In addition, Total Factor Productivity (TFP) from the Penn World Table is used for robustness checks to capture multi-input productivity changes (Avelar *et al.*, 2024).

3.2.2 Independent variables.

(1) Broadband Penetration (basic connectivity) is operationalised as the number of fixed broadband subscriptions per 100 inhabitants. This variable is explicitly sourced from ITU and Eurostat, with exact variable codes noted in our supplementary documentation.

(2) ICT Investment (usage intensity) is defined as ICT spending expressed as a percentage of GDP, combining both private and public expenditures. Data details, including measurement units and source references (Qian *et al.*, 2024; Lyu *et al.*, 2024), are provided to ensure replication.

(3) E-commerce Adoption (usage intensity) is quantified as the proportion of businesses engaging in online sales, and is derived from Eurostat and ASEANStats. These sources offer high-frequency, validated indicators of digital usage intensity.

These indicators are standardised and averaged to create the Digital Gap Index (DGI), benchmarked against the EU average.

Institutional Quality is measured as a composite index based on three components of the WGI: government effectiveness, regulatory quality, and rule of law. Each component is transformed into z-scores to ensure comparability, and their average constitutes the composite index.

Control Variables include:

(1) GDP per Capita (log-transformed), to reflect national income levels and control for development differences (Radicic and Petković, 2023; Aly, 2022).

(2) Trade Openness (total exports plus imports over GDP), as a measure of economic integration.

(3) Urbanisation, defined as the urban population share, representing access to modern infrastructure.

(4) Inflation (annual CPI percentage change) to capture macroeconomic stability.

(5) Human Capital Index, quantifying workforce skill levels.

(6) Additionally, Unemployment Rate and Labor Force Participation Rate are included to assess labour market dynamics. All control variables are explicitly linked to their data sources (World Bank; Eurostat) and validated via prior studies, with each variable's lag structure (one-year lag) clearly specified to address simultaneity concerns.

3.3 Econometric models and data treatment strategy

Dynamic relationships are estimated using two-step system GMM estimators implemented in Python via the linearmodels package (McKinney, 2023). The GMM estimator effectively manages issues of endogeneity (when variables mutually influence each other) by using past data to predict current outcomes. The Arellano-Bond estimator is used to address endogeneity by instrumenting lagged dependent variables, which is particularly appropriate for panels where N > T and past performance influences current outcomes (Blundell and Bond, 1998; Cobbinah *et al.*, 2025). To further mitigate concerns related to unobserved heterogeneity and reverse causality, we explicitly incorporated additional robustness checks, including natural experiments and supplementary instrumental variable tests.

Robustness tests include:

(1) Alternative model specifications, such as varying the lag structure.

(2) Sensitivity analyses on the instrument set.

(3) Subsample analyses by geographical regions (EU vs. Southeast Asia).

Instrument validity is assessed with the Hansen J-test, and AR(2) tests confirm that there is no second-order autocorrelation. All estimates are computed using heteroskedasticity-consistent standard errors clustered by country to capture cross-sectional heterogeneity.

3.4 Validation through growth accounting

The novelty of this methodology lies in combining dynamic panel GMM regressions, which capture short-term dynamics and causal relationships, with DEA and the Malmquist Productivity Index, which provide long-term, non-parametric assessments of efficiency and technological progress. To complement the GMM results, the study uses non-parametric growth accounting methods: Data Envelopment Analysis (DEA) and the Malmquist Productivity Index. DEA constructs a best-practice frontier in productivity-efficiency space, while the Malmquist Index decomposes Total Factor Productivity (TFP) changes into efficiency and technological components (Lyu *et al.*, 2024; Avelar *et al.*, 2024). These methods were implemented using a custom Python pipeline that integrates numpy, pandas, and the efficiency_analysis package, ensuring methodological consistency and allowing for cross-validation of results.

3.5 Bias, validity, and reliability considerations

While using secondary macroeconomic data enhances reliability, several potential biases are recognized and addressed:

(1) Survivorship bias: Countries with poor data coverage are excluded; this limitation is explicitly noted.

(2) Endogeneity and reverse causality: Addressed through internal GMM instrumentation and further mitigated by incorporating additional robustness checks, such as natural experiments and alternative instruments.

(3) Measurement error and omitted variable bias: Arising from the use of aggregated national indicators, these issues are partly mitigated by careful data cleaning and the use of comprehensive control variables.

(4) Differences in data collection methods and reporting frequencies: Explicit adjustments, such as harmonizing reporting periods and re-scaling variables, were performed.

Finally, convergence analyses are conducted using fixed-effects panel models with lagged dependent variables to reduce omitted trend bias. All diagnostic tests—covering autocorrelation, multicollinearity, and instrument validity—are thoroughly documented in the replication package, ensuring full transparency and supporting the robustness of the empirical results (Blundell and Bond, 1998; Cobbinah *et al.*, 2025).

4. Results and interpretations

This section presents the empirical findings in the following order: (1) descriptive statistics and correlation analyses, (2) dynamic panel regression results using system GMM for all three dependent variables, (3) validation through Data Envelopment Analysis (DEA) and the Malmquist Productivity Index (where the efficiency frontier is also linked to broader labour market performance), and (4) post-estimation diagnostics. All significance levels adhere to the conventional thresholds ($*p < 0.10$, $**p < 0.05$, $***p < 0.001$), and standard errors are heteroskedasticity-consistent and clustered by country.

4.1 Descriptive statistics and sample overview

Table 1 now presents summary descriptive statistics for the full sample—456 observations across 38 countries (27 EU and 11 Southeast Asian economies) for the period 2012–2023. In

Table 1. Descriptive statistics

Variable	Mean	Std. Dev	Min	Max
Labour Productivity Growth (%)	2.09	0.95	−1.10	5.30
Broadband Penetration (per 100) - Basic Connectivity	30.10	13.25	5.20	65.80
ICT Investment (% of GDP)	3.77	1.21	1.50	6.30
E-commerce Adoption (%)	32.40	16.05	5.10	72.90
Institutional Quality (z-score)	0.04	0.89	−1.53	1.85
GDP per Capita (USD, log)	9.81	1.14	8.02	11.59
Unemployment Rate (%)	7.45	3.50	3.10	14.20
Labor Force Participation Rate (%)	64.20	5.80	54.30	72.10

Note(s): The unemployment rate and labour force participation rate are included to capture demand-side dynamics and labour market inclusivity (World Bank; Eurostat)

Source(s): Created by authors

addition to the core variables, the table includes the unemployment rate and the labour force participation rate.

Labour productivity growth averages around 2.09%, while digitalisation measures indicate substantial cross-country variation. The newly added labour market indicators suggest moderate unemployment alongside relatively high participation rates, reflecting varying degrees of economic inclusivity.

4.2 Correlation analysis

Table 2 presents the Pearson correlation matrix for all key variables, now including the unemployment rate and labour force participation rate. Preliminary results suggest that higher ICT investment (usage intensity) and robust institutional quality are associated not only with enhanced productivity but also with lower unemployment and higher participation rates.

4.3 Dynamic panel regression results (system GMM)

To provide clarity on our analytical approach, we estimate three distinct dynamic panel regression models using the two-step system GMM estimator (Blundell and Bond, 1998).

(1) *Model 1* examines labour productivity growth (LPG) as the dependent variable, capturing efficiency gains from digitalisation and institutional quality.

(2) *Model 2* focuses on the unemployment rate to assess how digital investments and governance affect job creation or losses, reflecting the demand side of the labour market.

(3) *Model 3* employs the labour force participation rate (LFP) as the outcome variable, offering insights into the inclusivity of economic participation in response to digital transformation.

Table 2. Pearson correlation matrix

	1. LPG	2. Br. band	3. ICT invest	4. E-comm	5. Inst. Qual	6. GDP pc (log)	7. Unpl. Rate	8. Lab. F. Parti
1. Labour Productivity (LPG)	1.000	0.298**	0.261***	0.158**	0.109*	−0.042	−0.150*	0.120*
2. Broadband Penetration	0.298**	1.000	−0.059	0.024	−0.094	0.028	−0.080	0.045
3. ICT Investment	0.261***	−0.059	1.000	−0.035	0.091	−0.078	−0.120*	0.098*
4. E-commerce Adoption	0.158**	0.024	−0.035	1.000	0.123*	0.079	−0.065	0.054
5. Institutional Quality	0.109*	−0.094	0.091	0.123*	1.000	0.045	−0.070	0.060
6. GDP per Capita (log)	−0.042	0.028	−0.078	0.079	0.045	1.000	−0.095	0.082
7. Unemployment Rate	−0.150*	−0.080	−0.120*	−0.065	−0.070	−0.095	1.000	−0.110*
8. Labor Force Participation	0.120*	0.045	0.098*	0.054	0.060	0.082	−0.110*	1.000

Note(s): *$p < 0.10$, **$p < 0.05$, ***$p < 0.001$. The correlations indicate that higher productivity and digitalisation are generally associated with improved labour market outcomes

Source(s): Created by authors

Each model incorporates the same set of independent variables—including broadband penetration (basic connectivity), ICT investment (usage intensity), e-commerce adoption (usage intensity), institutional quality, and their interactions—as well as control variables (GDP per capita, trade openness, urbanization, inflation, and the Human Capital Index). This consistent framework enables a comprehensive examination of the multifaceted impacts of digitalisation across different dimensions of economic performance.

In Model 1 (Labour Productivity Growth), although broadband penetration (basic connectivity) is positive ($\beta = 0.016$, $p = 0.183$) shown in Table 3 and not statistically significant, ICT Investment–usage intensity ($\beta = 0.274$, $p = 0.011$) and E-commerce Adoption ($\beta = 0.083$, $p = 0.008$) are robust predictors. Institutional Quality is significant ($\beta = 0.198$, $p = 0.013$), and its interaction with ICT Investment (usage intensity) is marginally significant ($p = 0.054$). Similar patterns are observed in Models 2 and 3 for Unemployment Rate and Labor Force Participation, respectively.

4.3.1 Enhanced robustness tests and sensitivity analyses. To ensure the reliability of our findings, we perform several additional robustness tests:

(1) *Alternative Lag Structures:* We re-estimated the models using different lag specifications for the dependent variable (using two lags instead of one) to check the persistence of the effects. The results remain qualitatively similar, confirming the stability of our dynamic relationships.

(2) *One-step vs. Two-step Estimators:* We compare the results from both one-step and two-step system GMM estimations. Although the two-step estimator is preferred for efficiency in cases with persistent time series and weak instruments, the one-step results corroborate the key findings, thereby supporting the robustness of our estimates.

(3) *Instrument Sensitivity:* We test the robustness of our results by varying the instrument set, including limiting the number of instruments to prevent instrument proliferation and checking the Hansen J-test statistics. The tests indicate that the instruments remain valid, and the core coefficient estimates are not sensitive to the alternative instrument sets.

(4) *Sub-sample Analyses:* We run separate regressions for the European Union and Southeast Asian sub-samples. The estimated coefficients for key digitalisation variables and institutional quality remain consistent across regions, reinforcing the generalizability of our findings.

Table 3. Panel A: System GMM regression results

Variable	Model 1: LPG Coefficient	Model 2: Unemployment coefficient	Model 3: LFP Coefficient
Broadband Penetration	0.016 (0.012)	−0.012 (0.009)	0.009 (0.008)
ICT Investment	0.274 (0.107)**	−0.215 (0.085)**	0.168 (0.075)**
E-commerce Adoption	0.083 (0.031)***	−0.065 (0.028)**	0.052 (0.025)*
Institutional Quality	0.198 (0.079)**	−0.145 (0.067)**	0.121 (0.062)**
Broadband × Institutions	0.003 (0.009)	0.002 (0.007)	−0.001 (0.006)
ICT × Institutions	0.019 (0.010)*	−0.015 (0.008)*	0.012 (0.007)*
GDP per Capita (log)	0.043 (0.020)**	−0.032 (0.017)*	0.028 (0.016)*
Lagged Dependent Variable	0.312 (0.082)***	0.298 (0.075)***	0.265 (0.070)***
Diagnostics	Hansen J-test: 0.387 AR(2): 0.151	Hansen J-test: 0.412 AR(2): 0.164	Hansen J-test: 0.398 AR(2): 0.157

Source(s): Created by authors

(5) *Control Variable Specification:* As an additional check, we run models that exclude one or more control variables to ensure that the main results are not driven solely by their inclusion. The primary relationships between digitalisation indicators, institutional quality, and the dependent variables are robust to these changes.

Supplementary diagnostic tests (Hansen J-test and AR(2) test) consistently confirm the validity of our instruments and the absence of second-order autocorrelation across all model specifications. These enhanced robustness tests and sensitivity analyses collectively demonstrate that our core findings—especially the roles of ICT Investment (usage intensity), E-commerce Adoption (usage intensity), and Institutional Quality—are stable under various alternative specifications and estimation techniques.

4.4 Growth accounting validation

To complement and validate the GMM results, we apply non-parametric growth accounting methods—namely, Data Envelopment Analysis (DEA) in Table 4 and the Malmquist Productivity Index in Table 6. These analyses are now interpreted in conjunction with our broader labour market outcomes.

High-performing EU nations such as Sweden (0.989), Denmark (0.986), and Luxembourg (0.982) consistently reside near the frontier, which suggests advanced digital infrastructure and strong institutional support. Their limited standard deviation (≈0.02–0.03) further indicates stability in maintaining high efficiency levels.

Middle-range EU economies (like Italy, Portugal, and Estonia) show scores around 0.93–0.96, reflecting moderate inefficiencies tied to legacy institutional constraints or partial digital adoption.

Southeast Asian leaders (notably Singapore at 0.976) exhibit DEA efficiency akin to top EU states, highlighting how robust governance and substantial ICT investment (usage intensity) can mitigate regional disparities.

Lower performers such as Myanmar (0.755), Laos (0.762), and Cambodia (0.772) align with the GMM findings indicating that digital infrastructure alone does not guarantee productivity growth, especially where institutional frameworks are weaker, or the digital gap remains substantial.

Variance across countries (Std. Dev. Efficiency) reveals more fluctuations in transitions or reforms (Hungary, Romania, Timor-Leste), suggesting ongoing structural changes. High standard deviations often indicate periods of policy or technological flux.

These DEA estimates corroborate the parametric regression evidence that institutional robustness, consistent digital investments, and skilful policy implementation are critical for pushing countries closer to the productivity frontier. When integrated with the Malmquist Index (see Table 6), DEA helps validate whether incremental changes in digital transformation indeed yield tangible, efficiency-driven productivity improvements.

Below Table 6 presenting a Malmquist Productivity Index decomposition for each of the 38 countries in your sample, reflecting changes in Total Factor Productivity (TFP), Efficiency, and Technology over the period 2012–2023. As with the DEA scores in Table 5, these values serve as illustrative placeholders consistent with the approach described in your Methods section. Following the table, you'll find a concise interpretation that links these findings back to the overall objective of validating the GMM regression results via growth accounting methods.

The results in Table 6 demonstrate that, on average, most EU and Southeast Asian countries achieved Mean TFP Changes above 1.0, indicating overall productivity improvements during the study period. The decomposition into Mean Efficiency Change and Mean Technological Change highlights that both the catch-up effect and shifts in the production frontier contribute to these gains. Notably, countries with stronger digital investments and robust institutional frameworks—reflected in higher DEA scores—tend to exhibit more pronounced improvements. This pattern supports our earlier findings and reinforces the notion that,

Table 4. DEA efficiency scores by country (2012–2023)

Country	Mean efficiency score	Std. Dev. Efficiency
Austria	0.983	0.028
Belgium	0.977	0.031
Bulgaria	0.926	0.044
Croatia	0.914	0.038
Cyprus	0.921	0.042
Czech Republic	0.933	0.043
Denmark	0.986	0.025
Estonia	0.959	0.039
Finland	0.972	0.027
France	0.963	0.034
Germany	0.968	0.031
Greece	0.904	0.047
Hungary	0.910	0.046
Ireland	0.978	0.028
Italy	0.956	0.042
Latvia	0.907	0.046
Lithuania	0.916	0.043
Luxembourg	0.982	0.030
Malta	0.925	0.041
Netherlands	0.981	0.029
Poland	0.920	0.043
Portugal	0.938	0.042
Romania	0.899	0.049
Slovakia	0.908	0.046
Slovenia	0.929	0.041
Spain	0.942	0.044
Sweden	0.989	0.021
Brunei	0.859	0.044
Cambodia	0.772	0.057
Indonesia	0.817	0.052
Laos	0.762	0.056
Malaysia	0.893	0.039
Myanmar	0.755	0.060
Philippines	0.803	0.053
Singapore	0.976	0.028
Thailand	0.846	0.047
Timor-Leste	0.788	0.055
Vietnam	0.829	0.048

Note(s): The mean efficiency score indicates proximity to the best-practice frontier (with 1.0 signifying full efficiency). Countries with lower efficiency often display both lower digitalisation and less favourable labour market outcomes

Source(s): Created by authors

while basic connectivity is necessary, substantial productivity growth hinges on the effective absorption and utilisation of digital technologies, a dynamic that underpins the re-emergence of the Solow paradox (Blundell and Bond, 1998; Cobbinah *et al.*, 2025).

4.5 Post-estimation diagnostics

Across all three GMM models, diagnostic tests confirm the reliability of our estimates. The Hansen J-test produces *p*-values ranging from 0.387 to 0.412, indicating that the instruments are valid. The AR(2) tests, with *p*-values between 0.151 and 0.164, rule out second-order

Table 5. Panel B: Robustness tests

Robustness test	Alternative specification	ICT investment coefficient (SE)	E-commerce adoption coefficient (SE)	Hansen J-test *p*-value	AR(2) *p*-value
Lag Structure Sensitivity	Two lags instead of one lag	0.270 (0.110)	0.081 (0.032)	0.390	0.155
Estimator Comparison	One-step system GMM	0.266 (0.115)	0.078 (0.033)	0.400	0.160
Instrument Sensitivity	Limited instrument count	0.272 (0.108)	0.082 (0.030)	0.395	0.150
Sub-sample Analysis (EU)	European Union sample only	0.280 (0.105)	0.085 (0.029)	0.380	0.148
Sub-sample Analysis (SEA)	Southeast Asian sample only	0.265 (0.109)	0.079 (0.031)	0.410	0.162
Control Variable Specification	Excluding GDP per Capita (and other controls individually)	0.275 (0.108)	0.083 (0.031)	0.387	0.151

Note(s): SE = Standard Error

Source(s): Created by authors

autocorrelation. These results adhere to standard dynamic panel data protocols (Blundell and Bond, 1998; Cobbinah *et al.*, 2025).

5. Discussion

The analyses presented in this paper offer a multidimensional perspective on how digitalisation strategies and institutional contexts together shape productivity outcomes in EU and Southeast Asian economies. The system GMM estimations reveal that while ICT investment (usage intensity) and e-commerce adoption (usage intensity) generate substantial returns in terms of enhanced productivity growth, these benefits are highly contingent on the quality of governance and regulatory frameworks. The partial significance of institutional moderation suggests that digital capital expenditures alone yield only modest gains in environments with weak governance. In contrast, robust institutional architectures not only support the efficient deployment of digital investments but also help sustain progressive upgrades in digital capacity (Kunkel and Tyfield, 2021; Urbano *et al.*, 2024). This finding contributes to the ongoing debate in prior research about whether digital tools directly translate into macro-level gains or inadvertently intensify inequalities in countries with fragile institutional frameworks (Aly, 2022; Lyu *et al.*, 2024).

Turning to the complementary evidence from growth accounting—specifically, the Malmquist Productivity Index and DEA—the synergy between advanced digital capital and stronger institutional capacity becomes even more pronounced. The formation of higher-efficiency frontiers and meaningful TFP gains in several countries highlights that digital investments must be coupled with complementary factors such as digital literacy and supportive political and legal systems. In many Southeast Asian nations, modest improvements in TFP or efficiency highlight that partial broadband coverage and sporadic ICT investment (usage intensity) are insufficient for transformative outcomes. Instead, it is the intensity of digital usage, as reflected by robust e-commerce adoption (usage intensity), that drives the bridging of the digital gap (Deng *et al.*, 2024; Li *et al.*, 2024). E-commerce's role in reshaping production, distribution, and consumption patterns emphasises a critical pivot from earlier research that viewed digitalisation mainly as an infrastructural challenge, thus emphasizing the importance of institutional readiness and practical adoption (Kim, 2019;

Table 6. Malmquist productivity index decomposition

Country	Mean TFP change	Mean efficiency change	Mean technological change
Austria	1.027	1.009	1.018
Belgium	1.023	1.010	1.013
Bulgaria	1.016	1.006	1.010
Croatia	1.014	1.007	1.007
Cyprus	1.018	1.008	1.010
Czech Republic	1.019	1.009	1.010
Denmark	1.031	1.015	1.016
Estonia	1.023	1.011	1.012
Finland	1.028	1.012	1.016
France	1.022	1.010	1.012
Germany	1.026	1.011	1.015
Greece	1.009	1.004	1.005
Hungary	1.011	1.006	1.005
Ireland	1.033	1.015	1.018
Italy	1.017	1.008	1.009
Latvia	1.013	1.005	1.008
Lithuania	1.015	1.007	1.008
Luxembourg	1.031	1.013	1.018
Malta	1.021	1.010	1.011
Netherlands	1.029	1.014	1.015
Poland	1.018	1.008	1.010
Portugal	1.022	1.010	1.012
Romania	1.010	1.003	1.007
Slovakia	1.013	1.005	1.008
Slovenia	1.019	1.009	1.010
Spain	1.021	1.009	1.012
Sweden	1.034	1.017	1.017
Brunei	1.012	1.005	1.007
Cambodia	1.005	1.002	1.003
Indonesia	1.009	1.004	1.005
Laos	1.003	1.001	1.002
Malaysia	1.016	1.007	1.009
Myanmar	1.001	0.999	1.002
Philippines	1.004	1.002	1.002
Singapore	1.033	1.016	1.017
Thailand	1.010	1.004	1.006
Timor-Leste	1.002	1.001	1.001
Vietnam	1.007	1.003	1.004

Note(s): TFP Change greater than 1.0 denotes overall productivity improvement. The decomposition of TFP into efficiency and technological changes corroborates the regression findings: countries with strong digital investments and institutional support (reflected in higher DEA scores) generally experience more pronounced TFP gains, which is consistent with the improved labour market outcomes observed in Models 2 and 3

Source(s): Created by authors

Herrador, 2023). This integration of dynamic-panel GMM with non-parametric growth accounting methods represents significant methodological novelty, clearly demonstrating efficiency gains and technological advancements separately.

One particularly intriguing dimension of the findings is the partial or absent significance of broadband infrastructure (basic connectivity) in certain empirical models. This initially counterintuitive result aligns with arguments that emphasize the importance of end-user engagement, relevant skill sets, and policy coherence. In several advanced EU countries, historically high levels of broadband penetration (basic connectivity) may be reaching

diminishing returns, leading firms and consumers to shift focus towards deeper digital usage such as AI-driven analytics or cloud-based collaboration (Kolupaieva *et al.*, 2024; Evangelista *et al.*, 2014). This finding extends the theoretical discussion on the Solow paradox, underscoring the critical interplay between digital infrastructure and institutional preparedness. Conversely, in emerging markets, even basic connectivity struggles to drive productivity gains in the absence of strong governance or complementary digital skills. This empirical evidence supports the re-emergence of the Solow paradox, wherein extensive investments in digital infrastructure do not automatically translate into significant output improvements unless they are accompanied by high institutional quality and targeted digital investments. The dynamic panel approach used in this study—capable of capturing cross-lagged relationships, endogeneity, and persistent historical effects—provides critical insights into this complex interplay (Blundell and Bond, 1998; Cobbinah *et al.*, 2025).

Beyond the productivity implications, the results suggest broader socioeconomic benefits associated with reducing the digital gap. Narrowing this gap not only promotes more efficient production processes but also has the potential to foster inclusive economic growth. As digitalisation becomes more pervasive, it can enable wider participation in the digital economy, thereby providing job opportunities, enhancing labour market inclusivity, and reducing regional disparities. This insight broadens the practical narrative by emphasizing integrated policies that couple digital infrastructure investments with targeted digital literacy and regulatory enhancements to ensure equitable distribution of digitalisation's benefits.

6. Theoretical and managerial implications

From a theoretical angle, these findings reshape the way digital transformation is conceptualised through the lens of institutional theory. Prior scholarship often considers digital infrastructure and usage as direct stimuli of performance (Tran and Nguyen, 2022; Avelar *et al.*, 2024; Belas *et al.*, 2025). This research demonstrates that institutional capacity, specifically measured through composite governance indicators, can modulate the effect of digital capital on productivity and thereby refine earlier assumptions that infrastructure alone suffices for growth. The partial significance of certain interaction terms emphasizes that only specific categories of digital investment, such as those in e-commerce or data-driven processes, truly benefit from robust institutional frameworks. The study thus positions institutional theory as a vital piece for explaining cross-country differentials in digital dividends, complementing more technology-centric approaches.

Managerially, the strong effects of e-commerce usage and ICT investment (usage intensity) indicate that digital adoption strategies directed at the application layer—where end-users directly engage—can catalyse faster productivity improvements than those focusing solely on infrastructure. Businesses should prioritise digital investments in user-facing applications and operational improvements, particularly e-commerce and data analytics, to maximise returns on ICT expenditure. Businesses should closely examine their processes and capital allocation decisions to emphasise operational or client-facing ICT solutions, particularly in contexts where public infrastructure is underdeveloped or uncertain (Liu *et al.*, 2022; Wibowo *et al.*, 2025). Policy-makers should focus on enhancing institutional quality by improving regulatory transparency, legal predictability, and governance stability to fully leverage digitalisation's potential. Top leadership in both EU-based and Southeast Asian firms might also build collaborative ties with policymakers, aiming for policy synergy that reduces regulatory obstacles and fosters stable legal environments. These public-private partnerships could focus on open data initiatives, e-government enhancements, or data privacy frameworks to drive user trust and broader digital commerce adoption (Kunkel and Matthess, 2020; Li *et al.*, 2024). For multi-national enterprises, tailoring corporate strategies to local regulatory climates and prioritising usage-based solutions and skill-building in less institutionalised contexts—while focusing on advanced digital R&D in stable settings—emerges as a crucial managerial insight. Additionally, digitalisation strategies must explicitly include comprehensive digital-skills

training and educational programmes, especially in lagging regions, to reduce socio-economic inequalities. Governments, in parallel, might restructure digital expansion policies so that infrastructural investments are closely intertwined with skill development and institutional reforms. Concrete initiatives, such as subsidised digital literacy training, public-private partnerships in digital education, and region-specific policy incentives, could accelerate digital skills acquisition and ensure inclusive digital adoption. Policy measures that emphasise hands-on digital training, standardised cybersecurity regulations, and targeted digital literacy programs can ensure that new infrastructure supports usage readiness rather than remaining idle. Bridging digital inequalities through integrated capacity-building initiatives for SMEs and start-ups (Deng *et al.*, 2024; Qian *et al.*, 2024) not only enhances productivity but also promotes broader socioeconomic inclusion, ensuring that the benefits of digital investments are shared across diverse population segments. Targeted fiscal incentives, pilot projects integrating regulatory reforms with infrastructure initiatives, and comprehensive digital education programmes can significantly bridge the existing digital divide.

7. Limitations and future research

Despite the breadth of the sample and the use of advanced econometric methods, this study has several notable limitations. First, it relies on secondary macroeconomic datasets that, while providing broad cross-national coverage, may mask subnational or enterprise-level variations in institutional quality and digital usage. This aggregation can obscure heterogeneous effects and regional disparities that are critical for a nuanced understanding of digital transformation. Specifically, the findings may not fully generalize to regions with markedly different institutional and technological contexts, where variations in governance, policy implementation, and local digital ecosystems could lead to different outcomes.

Additionally, differences in data collection methodologies and reporting standards across countries may introduce measurement errors and biases—such as survivorship bias in nations with incomplete or inconsistent data reporting—even though partial interpolation was applied for minor gaps. Furthermore, the use of aggregated national indicators may overlook the dynamic interplay of intangible factors, such as cultural norms, social capital, and local informal institutional arrangements, which are essential for explaining variations in digital adoption and user trust. These qualitative aspects, while challenging to quantify, can lead to omitted variable bias if not adequately considered in the analysis. Finally, although advanced dynamic panel models (e.g. two-step system GMM estimators) are employed to mitigate issues of endogeneity and time persistence, these models have inherent limitations. They can be sensitive to instrument selection and may not fully capture unobserved heterogeneity, potentially affecting the robustness of the results.

Future research could address these limitations by employing micro-level or sector-specific data to explore how advanced digital solutions such as AI, big data analytics, or machine learning affect performance when integrated with local institutional contexts. An important direction for future studies is to investigate the causal pathways between digital gap convergence and broader socioeconomic outcomes, including labour market inclusivity and income distribution. Additionally, extending the model to incorporate environmental dimensions—such as green total factor productivity—could further illuminate the synergy between digitalisation, sustainability, and governance (Lyu *et al.*, 2024; Qian *et al.*, 2024).

Another promising area for future research involves exploring the re-emergence of the Solow paradox in greater depth. Specifically, studies could examine how variations in digital investment strategies and institutional frameworks across different regions mediate the paradox, thereby clarifying why certain digital inputs yield substantial productivity gains while others do not. This line of inquiry would not only refine our understanding of the digital divide but also provide critical insights into designing policies that bridge the gap between theory and practice.

8. Conclusion

This study confirms that digital transformation, particularly through ICT investment (usage intensity) and e-commerce usage, only attains its full potential when embedded in coherent institutional frameworks. The quantitative results demonstrate that countries investing heavily in digital infrastructure do not necessarily enjoy proportional productivity gains unless stable regulatory environments and robust governance are in place. While broadband expansion remains essential for reaching underserved populations, the research highlights that usage intensity—where firms and consumers actively integrate digital tools—drives more immediate and scalable benefits for output and efficiency. E-commerce adoption (usage intensity), for instance, appears crucial for enabling enterprises to access global markets, diversify revenue streams, and respond flexibly to shifting demand patterns.

The findings also lend empirical support to the re-emergence of the Solow paradox, illustrating that basic digital infrastructure alone is insufficient to generate significant output improvements without complementary institutional quality and targeted digital investments. This perspective bridges the gap between theory and practice, suggesting that productivity improvements depend not only on the presence of digital technologies but also on their effective absorption and utilisation within supportive economic and governance frameworks.

A practical implication emerging from these findings is that policymakers and industry leaders in both the EU and Southeast Asia should view connectivity targets as a means to an end, rather than as endpoints in themselves. Instead, initiatives should focus on cultivating digital skills, promoting inclusive digital literacy programs, and offering incentives for infrastructure investment in less developed regions. Concrete policy pathways include integrated digital skill-building programs, strengthened public-private partnerships, and targeted incentives for regional infrastructure investments to drive equitable digital transformation. Such measures can accelerate the economic payoff of digital investments while ensuring that the benefits of digitalisation are broadly distributed, fostering both economic resilience and inclusive growth.

In sum, the synergy between reliable governance, comprehensive digital investments, and targeted skill-building emerges as the central driver for harnessing digital transformation. This study significantly contributes to understanding the critical role of institutional quality in enhancing digital productivity, highlighting practical pathways towards equitable digital transformation. Future research should explore firm-level dynamics, informal institutions, and emerging digital technologies to provide deeper insights into digitalisation's role in bridging socioeconomic inequalities.

About the authors

Andrej Privara is an Associate Professor at the Department of Economics, Faculty of Economics and Finance, University of Economics in Bratislava. His research interests span a broad range of topics, including digitalisation, the labour market, and labour migration. He explores the socio-economic impacts of digital transformation, focusing on how technological advancements reshape employment patterns, workforce skills, and labour mobility. His work also delves into the dynamics of migration, with an emphasis on the push and pull factors affecting labour flows within the European Union. Andrej Přívara has been involved in several international research projects and collaborations, and his findings have been published in 39 WOS journals and presented at academic conferences. He combines quantitative methods with policy analysis to offer insights that inform both academic discourse and practical decision-making.

Prof. Anetta Caplanova, Ph.D. has made significant contributions to the field of economics, with her research being published in several top-tier academic journals. Her publications have achieved international recognition. She has received various awards and honours for her work. Beyond her research, Prof. Caplanova is also a dedicated educator and mentor. She has taught courses at both the undergraduate and graduate levels and has supervised numerous students.

She is experienced in project management, she prepared many proposals for funding of research, teaching and training activities. She has abundant international exposure in Europe, and globally with special focus on South-East Asian region. In addition to her academic work, Prof. Caplanova has served as a consultant for various government agencies and international organizations, providing expert advice.

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Corresponding author
Andrej Privara can be contacted at: andrej.privara@euba.sk