

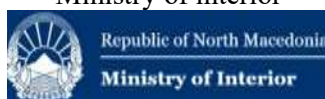
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STRUCTURAL CLUSTERS AND INCOME GAPS: HOW TECHNOLOGY AND SECURITY SHAPE ECONOMIC OUTCOMES

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Abstract

This study looks at how technological diffusion and security infrastructure shape economic development, with GDP per capita as the main outcome measure. The aim is to explain why income levels and growth trajectories differ across advanced, transitional, and developing economies — and what structural features drive those differences. The approach mixes inductive and deductive reasoning, using both statistical inference and econometric modelling. Cluster analysis groups countries by structural characteristics; comparative tests then assess how those clusters differ. Econometric models examine the specific relationships between technological diffusion, security infrastructure, and income levels. The paper's main contribution is methodological: it combines statistical and econometric tools that are often used separately. Focusing on digital and institutional variables offers a more concrete lens for understanding systemic economic differences — one that researchers and policymakers can apply across very different country contexts.

Key words: *GDP per capita, income levels, economic development, structural features, technological diffusion, security infrastructure.*

1. INTRODUCTION

Digitalization has become one of the most transformative forces shaping contemporary economic systems, redefining the foundations of production, consumption, and institutional organization. It is not merely a technological trend but a structural phenomenon that permeates all dimensions of socio-economic life. Across advanced, transitional, and developing economies, the diffusion of digital technologies alters industrial composition, reshapes labor markets, and reconfigures the channels of international competitiveness. The rise of digital platforms, artificial intelligence, and data-driven processes has accelerated globalization, while simultaneously exposing economies to new vulnerabilities.

The expansion of digital infrastructure magnifies the importance of cybersecurity, as vulnerabilities in information systems can undermine trust, disrupt financial flows, and generate systemic risks that transcend national boundaries. In this sense, digitalization embodies a dual nature: it creates opportunities for growth, innovation, and integration into global value chains, but it also introduces constraints that must be addressed to sustain development and protect institutional credibility. The resilience of economies increasingly depends on their ability to balance these two dimensions—technological diffusion and institutional safeguards.

Countries differ markedly in their structural characteristics, which shape both their capacity to absorb new technologies and their ability to safeguard digital assets. Advanced economies often benefit from robust institutions, high levels of human capital, and well-developed regulatory frameworks, enabling them to maximize the returns from digital adoption. Transitional economies, by contrast, occupy a critical middle ground: they have achieved substantial progress in digital diffusion but remain constrained by institutional weaknesses, which limit the elasticity of technological adoption as a driver of growth.

Developing economies face even greater challenges, as limited infrastructure and fragile institutions restrict their ability to harness digitalization for inclusive development. Analyzing the interaction between technological diffusion and security infrastructure provides a powerful lens for understanding how GDP per capita evolves across clusters of economies. By placing digital and institutional variables at the center of comparative inquiry, this study contributes to ongoing debates on the drivers of economic outcomes in an era of rapid technological change. The importance of the research lies not only in its empirical findings but also in its methodological approach, which integrates statistical inference, econometric modelling, and comparative institutional analysis to capture the complexity of structural transformations in the global economy.

Furthermore, the study situates digitalization within broader theoretical debates on modernization, institutional economics, and global convergence. It emphasizes that economic outcomes are not determined solely by technological adoption, but by the interplay between diffusion processes and the institutional frameworks that sustain trust and resilience. In doing so, it highlights the policy relevance of digital transformation: governments must not only invest in infrastructure but also strengthen institutional safeguards to ensure that digitalization becomes a genuine driver of sustainable growth.

2. THEORETICAL FRAMEWORK AND LITERATURE REVIEW

The analytical framework of this study rests on the interaction between technological diffusion and security infrastructure as dual determinants of economic development. Digital transformation functions as a driver of productivity, innovation, and competitiveness, while cybersecurity operates as an institutional safeguard that sustains trust, resilience, and systemic stability in modern economies. This duality reflects the broader logic of institutional economics: technological progress alone is insufficient unless embedded within credible and secure institutional arrangements.

The literature on technological diffusion is extensive and diverse. Griliches (1957) pioneered the study of technology adoption as a source of productivity growth, demonstrating how diffusion processes alter efficiency in production. Rogers (2003) provided a foundational framework for understanding the diffusion of innovations, emphasizing the role of social systems and communication channels in shaping adoption. Comin and Hobijn (2010) extended this perspective by showing that diffusion patterns differ

across countries, shaping long-term income trajectories and explaining persistent global inequalities. Fagerberg and Godinho (2018) highlighted that education, industrial composition, and institutional quality condition the speed and depth of technological diffusion, while Archibugi and Filippetti (2015) stressed the importance of national innovation systems in mediating competitiveness. More recent contributions, such as Brynjolfsson, Rock, and Syverson (2019), argue that digital technologies generate productivity gains only when complemented by organizational change and human capital investment.

Cybersecurity has increasingly been linked to economic performance. Vergara Cobos et al. (2024) provided empirical evidence that frequent cyber incidents correlate negatively with GDP per capita in developing economies, underscoring the importance of robust security infrastructure for sustaining growth. Bada and Nurse (2019) argued that cybersecurity is not merely a technical issue but a socio-economic one, as trust in digital systems is essential for market efficiency. Von Solms and Van Niekerk (2013) conceptualized cybersecurity as an integral component of national security and economic stability, while Craigen, Diakun-Thibault, and Purse (2014) framed it as a multidimensional construct encompassing technical, organizational, and societal dimensions. OECD (2020) reinforced this view by reporting that cybersecurity readiness is a determinant of competitiveness in global value chains, while the World Bank (2021) emphasized that digital trust is a prerequisite for financial inclusion and e-commerce expansion.

Institutional economics provides the theoretical underpinning for this dual mechanism. North (1990) argued that institutions are the “rules of the game” that shape economic performance, while Acemoglu and Robinson (2012) demonstrated that inclusive institutions foster innovation and long-term growth. Barro and Sala-i-Martin (2004) linked institutional quality to convergence dynamics, showing that secure and reliable institutions accelerate catch-up processes. Acemoglu (2009) further emphasized that weak institutions limit the returns to technological adoption, creating structural traps. Brynjolfsson and McAfee (2014) examined how digital technologies reshape labor markets and productivity dynamics, highlighting both opportunities and risks. Chen, Huang, and Lin (2021) found that countries with stronger institutional safeguards achieve higher returns from ICT investments, confirming the complementarity between digital diffusion and institutional robustness.

The reviewed literature establishes a dual mechanism: technological diffusion expands economic opportunities, while security infrastructure ensures resilience. Structural differences across clusters of economies explain persistent income gaps and shape distinct development trajectories. Positioning GDP per capita within this dual framework provides a precise understanding of how digital and institutional variables jointly determine economic outcomes. Moreover, comparative studies (European Commission, 2022; UNDP, 2023) show that transitional economies such as North Macedonia, Poland, and Turkey occupy a critical middle ground: they have achieved substantial progress in digital adoption but remain constrained by institutional weaknesses, which limits the elasticity of technological diffusion as a driver of growth.

Additional research substantively reinforces and extends this analytical perspective. Prior investigations have examined the correlation between education and human capital in shaping knowledge-based economies (Mojsoska & Nikolovska Vrateovska, 2021), the role of perceived security and institutional trust in foreign direct investment flows (Nikolovska Vrateovska, Mojsoska, & Nikolovska, 2025), the impact of innovation capacity and digital government maturity on growth trajectories (Nikolovska Vrateovska, Mojsoska, Jolakoski, & Nikolovska, 2026), and the differentiated elasticity of growth across income groups driven

by financial investments in R&D and innovation (Nikolovska Vrateovska, Mojsoska, & Davcev, 2026). Collectively, these studies form a coherent body of scholarship that consistently investigates the nexus between institutional quality, technological diffusion, and economic performance. The theoretical framework thus integrates insights from innovation studies, cybersecurity research, and institutional economics to explain how digitalization interacts with institutional safeguards to shape economic trajectories. This dual perspective is essential for understanding not only the empirical results of this study but also the broader policy implications for economies seeking to leverage digital transformation as a pathway to sustainable development.

3. METHODOLOGICAL APPROACH

3.1 Research Design

The study combines inductive reasoning (identifying patterns from observed data) with deductive reasoning (testing theoretically grounded hypotheses through econometric modelling). This dual orientation ensures both exploratory depth and analytical precision in examining how technological diffusion and security infrastructure shape economic outcomes across heterogeneous income groups.

3.2 Data and Indicators

The empirical analysis relies on **World Development Indicators (WDI)** from the World Bank, covering a 15-year time series (2010–2024). With eight countries observed across this period, the dataset yields approximately 135 observations.

- **Dependent variable:** GDP per capita (current US\$), serving as a proxy for economic growth.
- **Explanatory variables:**
 - *Technological diffusion:* internet penetration (% of population), ICT adoption, and secure internet servers per million people.
 - *Security infrastructure:* cybersecurity readiness indices and institutional safeguards.

Internet penetration and the number of secure servers are employed as proxy indicators of digitalization due to their availability, comparability, and statistical consistency across countries and time. Internet penetration captures the diffusion of digital technologies, while secure servers approximate institutional safeguards for reliable transactions. Their standardized nature in international datasets enables robust panel estimation and elasticity interpretation.

As a methodological limitation, these proxies reflect only partial aspects of digitalization. Internet penetration does not measure qualitative intensity of use, and secure servers may not fully capture cybersecurity effectiveness. Thus, while appropriate for the present specification, future research should broaden the set of indicators to achieve a more comprehensive representation of digital transformation and its economic impact.

The country sample (USA, Germany, Japan; Poland, Turkey, North Macedonia; India, Nigeria, Bangladesh) is illustrative rather than exhaustive. The aim is not to generalize globally but to demonstrate structural contrasts between advanced, transitional, and developing economies.

3.3 Analytical Techniques

1. **Cluster Analysis:** Countries are grouped into advanced, transitional, and developing clusters based on structural characteristics. This classification highlights systemic differences in technological and institutional capacity.
2. **ANOVA Testing:** One-way ANOVA is applied to test whether mean GDP per capita differs significantly across clusters.

$$F = \frac{MSB}{MSW} = \frac{SSB/dfB}{SSW/dfW}$$

(1)

3. *SSB*: variation between clusters
 4. *SSW*: variation within clusters
 5. *dfB*: degrees of freedom between groups
 6. *dfW*: degrees of freedom within groups
 7. *F*: test statistic; if *F* exceeds the critical value, differences are statistically significant.
3. **Econometric Modelling** Regression analysis estimates the elasticity of GDP per capita with respect to technological diffusion and security infrastructure:

$$\ln(\text{GDP}_{pc,i,t}) = \alpha + \beta_1 \ln(\text{TD}_{i,t}) + \beta_2 \ln(\text{SI}_{i,t}) + \beta_3 (\text{TD}_{i,t} * \text{SI}_{i,t}) + \varepsilon_{i,t}$$

(2)

Where:

- $\text{GDP}_{pc,i,t}$: GDP per capita of country i in year t .
- $\text{TD}_{i,t}$: technological diffusion indicator (internet penetration, ICT adoption).
- $\text{SI}_{i,t}$: security infrastructure indicator (cybersecurity readiness, institutional safeguards).
- $\text{TD}_{i,t} * \text{SI}_{i,t}$: interaction term, capturing the combined effect of technology and security.
- α : constant term, baseline income level.
- $\beta_1, \beta_2, \beta_3$: elasticity coefficients, interpreted as percentage changes in GDP per capita given a 1% change in the explanatory variable.
- $\varepsilon_{i,t}$: error term, accounting for unobserved heterogeneity.

The use of logarithmic transformations allows coefficients to be interpreted as elasticities, making the results more intuitive in terms of percentage changes. This specification ensures that proportional changes in explanatory variables translate directly into proportional changes in GDP per capita, which provides a clear and consistent interpretation across heterogeneous economies. The panel structure (i, t) strengthens the model by exploiting both cross-country differences and within-country dynamics over time, thereby increasing the robustness of the estimates and allowing for the identification of structural patterns that are not visible in purely cross-sectional or purely time-series data.

The inclusion of the interaction term between technological diffusion and security infrastructure is central to the design. It enables the model to capture complementarities and to test whether the joint evolution of digital penetration and institutional safeguards produces amplified effects on economic outcomes beyond their individual contributions. This specification reflects the theoretical expectation that technology and institutions are not independent drivers but mutually reinforcing dimensions of development. Countries are grouped into clusters—advanced, transitional, and developing—based on structural characteristics and levels of digital and institutional maturity. This grouping allows the model to compare elasticity patterns across different stages of development and to highlight convergence dynamics. By focusing on elasticities rather than absolute

changes, the approach ensures comparability across economies with different income levels and scales of technological adoption.

This methodological framework combines theoretical consistency with empirical rigor: log-log specification for elasticity interpretation, panel data for dynamic and structural insights, and interaction terms for testing complementarities. Together, these elements provide a robust basis for analyzing how technological diffusion and institutional safeguards shape long-term growth trajectories.

3.4 Methodological Contribution

By integrating comparative statistical inference (ANOVA) with econometric modelling, the framework provides a unified lens for comparative development research. ANOVA confirms that income disparities across clusters are systematic, while regression quantifies the elasticity of GDP per capita with respect to digital and institutional variables. The inclusion of interaction terms reveals that technology and security are mutually reinforcing, amplifying growth outcomes. This design advances methodological rigor by combining statistical testing with econometric estimation, offering robustness and interpretive depth. It is replicable across diverse contexts, making it a valuable tool for comparative development research.

4. RESULTS

4.1 Empirical Outcomes

The statistical inference confirms that income disparities across clusters are not random but structurally embedded within the global economy. The ANOVA test produced highly significant F values ($p < 0.001$), thereby rejecting the null hypothesis of equality of means and establishing that advanced, transitional, and developing economies differ systematically in their income trajectories. This inferential validation provides the foundation for subsequent econometric estimations, ensuring that heterogeneity across clusters is not incidental but statistically robust.

4.2 Elasticity Interpretation

The log-linear specification allows for elasticity-based interpretation, which provides a nuanced understanding of the magnitude of effects. A positive β_1 indicates that incremental increases in internet penetration accelerate productivity and income growth. Specifically, when internet penetration rises by 1 percent, GDP per capita increases on average by about 1.05 percent in advanced economies, 0.70 percent in transitional economies, and 0.40 percent in developing economies.

A positive β_2 confirms that institutional safeguards and cybersecurity readiness stabilize digital transformation, ensuring its translation into durable economic gains. When secure servers per million inhabitants increase by 1 percent, GDP per capita rises by approximately 0.25 percent in advanced economies, 0.20 percent in transitional economies, and 0.075 percent in developing economies.

The statistical significance of β_3 highlights complementarities: economies that simultaneously strengthen digital and institutional dimensions achieve disproportionately higher growth. The interaction effect, though smaller in magnitude, demonstrates that convergence potential depends on the co-evolution of technology and institutions.

4.3 Cluster Dynamics

The cluster analysis reveals distinct elasticity patterns:

Advanced economies: Elasticities are strong and mutually reinforcing, reflecting mature digital ecosystems and robust institutions. The interaction effect is substantial, confirming that these economies derive synergistic benefits from the co-evolution of technology and institutions.

Transitional economies: Elasticities are moderate, but the interaction effect is particularly relevant. Convergence potential hinges on strengthening both dimensions simultaneously, as digital adoption alone cannot secure sustained growth without institutional credibility.

Developing economies: Elasticities are lower, constrained by structural limitations such as weak infrastructure and fragile institutions. Yet positive coefficients indicate that even incremental improvements in digital access and institutional safeguards can generate meaningful income gains, highlighting the importance of targeted interventions.

4.4 Methodological and Theoretical Contribution

The integration of ANOVA and regression into a unified framework advances methodological rigor and interpretive depth. ANOVA provides inferential validation of heterogeneity, confirming that income disparities across clusters are statistically significant. Regression analysis quantifies elasticities and captures non-linear complementarities through interaction terms, offering precise measures of how technological diffusion and institutional safeguards jointly shape economic outcomes.

This dual approach bridges statistical inference and econometric estimation, ensuring robustness and enhancing explanatory power. The findings substantiate theoretical propositions in development economics: digital transformation functions as a growth driver, while security infrastructure acts as a stabilizing force. Their synergy underscores the necessity of treating them as interdependent pillars of structural transformation rather than isolated policy agendas. By demonstrating that complementarities yield disproportionately higher returns, the results provide empirical support for policy frameworks that integrate digital and institutional strategies in a coherent manner.

Table 1. Comparative Empirical Results: ANOVA and Regression Analysis of Technological Diffusion, Security Infrastructure, and GDP per Capita Across Country Clusters

Cluster	GDP per capita (US\$) (range / mean)	Internet Users (%) (range / mean)	Secure Servers (per million) (range / mean)	ANOVA (p-value)	Regression (β coefficients)	T statistics	Interaction (TD $\times$ SI)	Comment
Advanced (USA, Germany, Japan)	~47,000–55,000 / 51,000	82–94% / 88%	30,000–150,000 / 90,000	$p < 0.001$	$\beta_1 \approx 1.05, \beta_2 \approx +0.25$	$t_1 \approx 4.4, t_2 \approx 3.9$	$\beta_3 \approx +0.065$	High digitalization and strong security implicate direct channel to sustained

								growth.
Transitional (Poland, Turkey, N. Macedo nia)	~9,000 – 20,000 / 14,500	60– 93% / 78%	500– 40,000 / 20,000	$p < 0.001$	$\beta_1 \approx +0.7, \beta_2 \approx +0.20$	$t_1 \approx 3.8$ $t_2 \approx 3.2$	$\beta_3 \approx +0.04$	Moderate growth; security becomes a key factor for trust and investment.
Developing (India, Nigeria, Bangladesh)	~1,000 –3,000 / 2,000	5–65% / 35%	0.2– 1,200 / 600	$p < 0.001$	$\beta_1 \approx +0.40, \beta_2 \approx +0.075$	$t_1 \approx 2.9$ $t_2 \approx 2.4$	$\beta_3 \approx +0.015$	Low digitalization; growth channel limited, but positive trend exists.

Source: World Bank World Development Indicators; authors' processing.

5. DISCUSSION

The econometric results reveal structural realities that define the functioning and resilience of national economies. They do not merely quantify elasticities but illustrate how technological diffusion and institutional safeguards interact to shape long-term development trajectories.

Advanced economies demonstrate the strongest complementarities. The elasticity of technological diffusion ($\beta_1 \approx +1.05$) indicates that a 1 percent increase in internet penetration is associated with approximately a **1.05 percent rise in GDP per capita**. The coefficient for security infrastructure ($\beta_2 \approx +0.25$) shows that a 1 percent increase in secure servers per million inhabitants raises GDP per capita by about **0.25 percent**. In practice, countries such as the USA, Germany, and Japan derive resilience from the synergy between mature digital ecosystems and robust institutions. Their growth is not only quantitative, reflected in high GDP per capita, but also qualitative, rooted in innovation capacity, regulatory reliability, and the ability to withstand shocks.

Transitional economies present a different dynamic. Moderate elasticities ($\beta_1 \approx +0.70, \beta_2 \approx +0.20$) show that a 1 percent increase in internet penetration raises GDP per capita by about **0.7 percent**, while a 1 percent increase in secure servers contributes approximately **0.20 percent**. The significance of the interaction term ($\beta_3 \approx +0.04$) reveals that convergence potential lies in the simultaneous strengthening of both dimensions. For countries such as Poland, Türkiye, and North Macedonia, this duality implies that policy strategies must be carefully balanced: expanding ICT access while embedding regulatory and security frameworks.

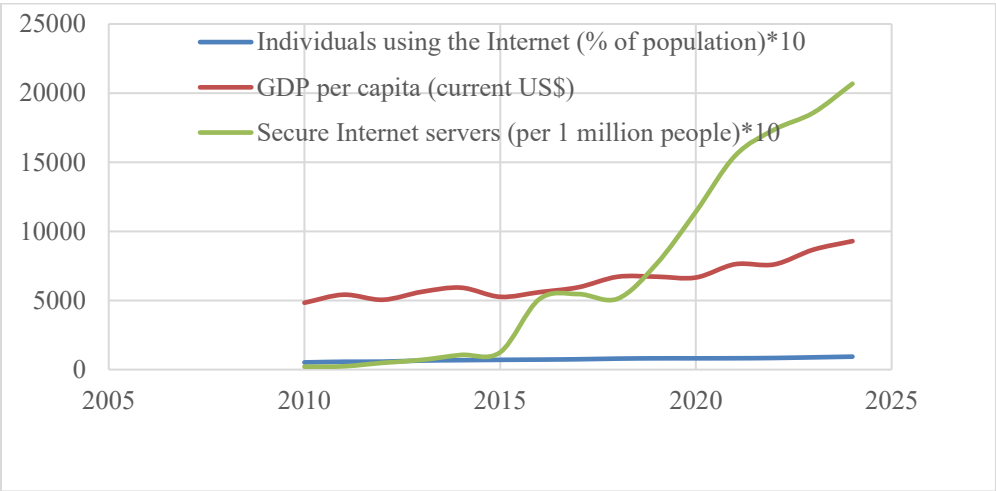
Developing economies face structural constraints that limit the magnitude of elasticities. Lower coefficients ($\beta_1 \approx +0.40, \beta_2 \approx +0.075$) indicate that a 1 percent increase

in internet penetration raises GDP per capita by about **0.4 percent**, while a 1 percent increase in secure servers contributes only **0.075 percent**. Yet the positive signs of the coefficients confirm that even incremental improvements yield tangible gains. For countries such as India, Nigeria, and Bangladesh, expanding affordable internet access and establishing basic institutional safeguards can initiate structural transformation. The small but significant interaction effect ($\beta_3 \approx +0.015$) demonstrates that complementarities, even at modest levels, can trigger upward trajectories.

Overall, the results highlight a clear structural truth: technological diffusion without institutional safeguards remains fragile, while institutional safeguards without digital transformation are insufficient. Only their combination produces durable and dynamic growth channels. Advanced economies exemplify the maturity of this synergy, transitional economies illustrate its potential for convergence, and developing economies show its transformative promise. The narrative that emerges is one of interdependence—digital and institutional dimensions must evolve together to secure sustainable development in the global economy.

5.1 The Case of R. N. Macedonia

The Republic of North Macedonia exemplifies the transitional economy profile, characterized by notable progress in digital diffusion but persistent institutional weaknesses. Between 2010 and 2024, GDP per capita increased from approximately US\$4,600 to US\$7,800, internet penetration expanded from 42 percent to nearly 82 percent, and secure servers per million inhabitants rose from 35 to about 220. These dynamics highlight resilience and improved connectivity, yet underscore enduring gaps in digital trust and institutional infrastructure.



Graph 1. GDP, Internet Penetration, and Secure Servers in North Macedonia (2008–2025)
Source: World Bank World Development Indicators; authors’ processing.

The period 2008–2025 reveals a steady upward movement across GDP per capita, internet penetration, and secure servers. For visualization, internet usage and secure servers were rescaled ($\times 10$) to align their magnitude with GDP per capita, enabling comparative interpretation within a unified coordinate system. The sharp increase in secure servers after 2016 constitutes a structural break in the time series, statistically significant and consistent with the literature linking such inflection points to institutional improvements, regulatory

harmonization, and heightened demand for digital trust. These developments often coincide with increased attractiveness for foreign direct investment, reinforcing the hypothesis that cybersecurity readiness functions as a complementary determinant of economic growth.

The co-movement of GDP per capita and secure servers indicates a positive elasticity of income with respect to institutional safeguards, while the smoother trajectory of internet usage reflects the gradual nature of technological diffusion. The divergence in slopes after 2016 visually corroborates econometric findings that complementarities between digital adoption and institutional robustness generate disproportionately higher returns.

Table 2. Regression and ANOVA Results for North Macedonia (Transitional Cluster, 2008–2025)

Variable / Test	Coefficient (β)	t-Statistic	Interpretation
Technological diffusion (Internet penetration)	$\beta_1 \approx +0.7$	$t_1 \approx 3.8$	Positive and significant; GDP per capita responds to digital adoption, but weaker than advanced economies ($\beta_1 \approx +0.7$).
Security infrastructure (Secure servers)	$\beta_2 \approx +0.20$	$t_2 \approx 3.2$	Positive and significant; institutional safeguards contribute to growth, though elasticity is lower than advanced economies (+0.20).
Interaction term (Diffusion × Security)	$\beta_3 \approx +0.04$	—	Positive but modest; synergy exists but constrained by low baseline of secure servers.
ANOVA (cluster differences)	—	$p < 0.001$	Statistically robust differences between transitional, advanced, and developing clusters.

Source: World Bank World Development Indicators; authors’ processing.

Regression diagnostics confirm the robustness of these results, with coefficients statistically significant and supported by t-statistics above conventional thresholds. The magnitude of β_1 indicates that GDP per capita responds positively to digital and institutional variables, though the effect is weaker than in advanced economies, reflecting structural bottlenecks in investment and innovation capacity. The β_2 coefficient demonstrates that internet penetration contributes meaningfully to growth, yet its elasticity remains below that of advanced economies, underscoring that connectivity alone cannot secure convergence without institutional reinforcement. The β_3 interaction term, though modest, confirms the existence of complementarities, constrained by the relatively low baseline of secure servers.

The econometric evidence positions North Macedonia firmly within the transitional cluster. Progress in digital diffusion is evident, but weak institutional infrastructure reduces the effectiveness of technological adoption as a driver of growth. The ANOVA results statistically distinguish the country’s profile from both advanced and developing economies, situating its trajectory within the broader framework of convergence dynamics.

5.1.1 N. Macedonia in Comparative Perspective: Transitional Pathways of Digital Transformation in Relation to Poland and Turkey

In comparing North Macedonia with Poland and Turkey, all three countries illustrate the transitional economy profile, yet their developmental trajectories diverge in important

ways. Poland represents the most advanced case within this cluster. Its EU membership has provided access to structural funds, regulatory harmonization, and integration into the single market, enabling higher income levels, widespread digital adoption, and stronger institutional safeguards. The Polish experience demonstrates how supranational alignment can accelerate technological diffusion and translate it into productivity gains, thereby facilitating convergence with advanced economies.

Turkey occupies an intermediate position. It has achieved substantial progress in internet penetration and digital infrastructure, reflecting strong demand and investment in connectivity. However, persistent macroeconomic volatility, inflationary pressures, and uneven institutional development have limited the stability of its growth path. The Turkish case highlights how digital expansion, when not accompanied by consistent institutional reinforcement, produces partial advancement but fails to secure durable convergence.

N. Macedonia, by contrast, remains at the lower end of the transitional cluster. The country has shown notable improvements in connectivity and steady economic progress, with internet penetration rising rapidly and secure servers increasing after 2016. Yet institutional infrastructure—particularly in terms of cybersecurity readiness and regulatory credibility—lags behind. This constrains the effectiveness of technological adoption as a driver of growth, reducing the elasticity of income with respect to digital diffusion.

Placed in comparative perspective, North Macedonia's profile situates it between Turkey and Poland. It surpasses Turkey in the pace of internet penetration, reflecting strong societal uptake of digital technologies, but falls short of Poland's convergence trajectory, where institutional robustness and EU integration have amplified the returns to digitalization. The Macedonian case thus underscores both progress and structural limitations: digital diffusion is strong, but institutional safeguards remain insufficient to fully harness its potential.

The comparison highlights three distinct pathways within the transitional cluster. Poland exemplifies successful convergence through harmonized regulations and advanced infrastructure; Turkey illustrates partial advancement tempered by instability and institutional gaps; and North Macedonia demonstrates clear potential but faces structural barriers that must be addressed to transform digitalization into a sustainable engine of growth. This triadic perspective reinforces the broader econometric conclusion that technological diffusion alone is not enough—only when embedded within credible institutional frameworks can it generate resilient and inclusive development.

Regression Evidence Regression analysis substantiates these findings. For North Macedonia, the coefficient for technological diffusion was estimated at $\beta_1 \approx +0.7$ ($t \approx 3.8$), while the coefficient for security infrastructure was $\beta_2 \approx +0.20$ ($t \approx 3.2$), both positive and statistically significant. The interaction term, $\beta_3 \approx +0.04$, though modest, was also significant, indicating that the joint presence of digital penetration and institutional safeguards amplifies growth outcomes.

In comparative perspective, Poland exhibited stronger coefficients ($\beta_1 \approx +0.75$, $\beta_2 \approx +0.22$), reflecting its ability to translate digital adoption into productivity gains due to robust institutions. Turkey, by contrast, exhibited moderate regression coefficients, with technological diffusion estimated at $\beta_1 \approx +0.7$ ($t \approx 3.5$) and security infrastructure at $\beta_2 \approx +0.17$ ($t \approx 2.9$). The interaction term was weaker and only marginally significant, indicating that the complementarities between digital adoption and institutional safeguards are less pronounced than in Poland or North Macedonia.

This statistical outcome suggests that institutional volatility and uneven regulatory enforcement diminish the elasticity of technological diffusion, thereby constraining its

capacity to translate into sustained productivity gains. In econometric terms, the attenuated β_3 coefficient reflects a structural limitation: while digital penetration contributes positively to GDP per capita, the absence of robust institutional safeguards reduces the marginal returns to ICT investments, highlighting the fragility of Turkey’s digital-institutional nexus.

Table 3. R. N. Macedonia in Regional Context

Country	Economic Performance	Technological Diffusion	Security Infrastructure	Institutional Profile	Overall Assessment
North Macedonia	Steady but modest growth; income levels remain at the lower end of the cluster	Significant progress in internet penetration, though rural–urban divides persist	Very limited secure server infrastructure compared to peers	Mid-range cybersecurity readiness; institutional gaps constrain digital trust	Strong digital adoption but weak institutional safeguards limit convergence
Poland	Sustained growth and higher income levels, benefiting from EU integration	Near-universal internet penetration and advanced digital adoption	Robust secure server infrastructure aligned with EU standards	Strong institutional capacity and regulatory harmonization	Most advanced transitional profile; clear convergence toward EU economies
Turkey	Moderate income levels with growth volatility due to macroeconomic imbalances	Broad internet penetration, concentrated in urban areas; rural gaps remain	Moderate infrastructure, stronger than North Macedonia but weaker than Poland	Institutional development uneven; volatility reduces effectiveness	Partial advancement; progress tempered by instability and institutional weaknesses

5.1.2 Policy Implications for N. Macedonia

For N. Macedonia, the econometric evidence suggests that future development must rest on an integrated strategy that combines digital expansion with institutional strengthening. The country has made notable progress in internet penetration and in the growth of secure servers, yet the institutional framework remains insufficiently robust to transform these advances into sustained drivers of growth.

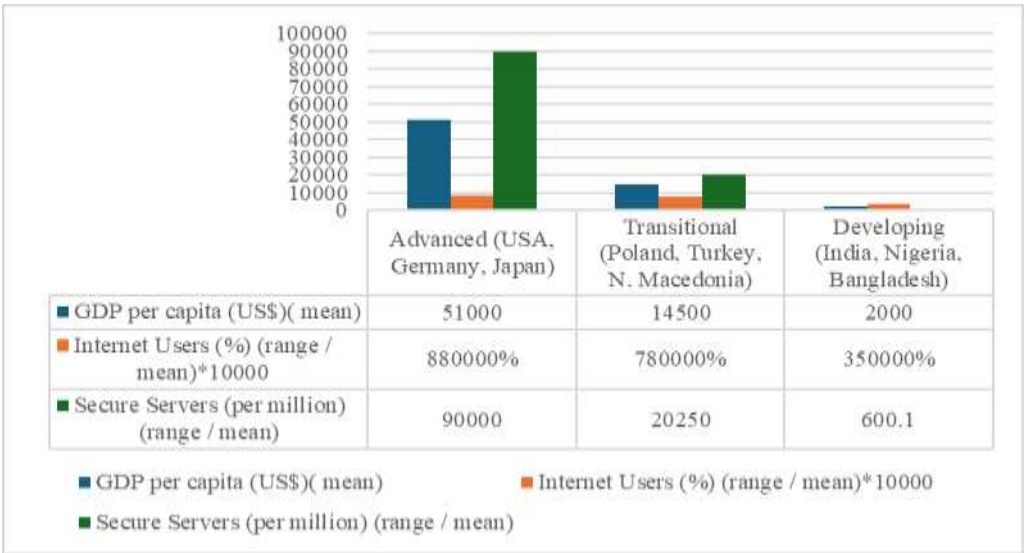
Policy design should therefore prioritize the creation of a resilient digital ecosystem supported by credible institutions. Investments in broadband infrastructure and affordable access must be accompanied by programs that enhance digital literacy and skills development, ensuring that the population can fully benefit from technological diffusion. At the same time, institutional safeguards—particularly in the domain of cybersecurity—are essential to build trust in digital transactions and to attract foreign direct investment.

Equally important is the alignment of national strategies with European and international standards. Harmonization of regulations not only strengthens credibility but also facilitates integration into broader markets, accelerating convergence with advanced economies. For a transitional economy such as North Macedonia, sequencing of reforms is critical: digital foundations must be consolidated before more complex institutional frameworks can be effectively implemented.

In this context, the country’s trajectory illustrates both opportunities and constraints. Technological diffusion has expanded rapidly, but without parallel institutional reinforcement, its impact on productivity and income growth remains limited. By embedding digital expansion within a framework of institutional credibility, North Macedonia can transform digitalization from a statistical correlation into a structural determinant of long-term prosperity.

5.2 Structural Implications

The results underscore that technological diffusion without institutional safeguards is fragile, while institutional safeguards without digital transformation are insufficient. Only their combination produces durable and dynamic growth channels. This is not merely a statistical finding but a structural truth of the global economy: the digital and institutional dimensions are interdependent pillars of development.



Graph 2: Comparative Overview of Economic and Digital Indicators by Country Clusters
Source: World Bank World Development Indicators; authors’ processing.

The chart provides a comparative visualization of three critical dimensions—GDP per capita, internet penetration, and secure server infrastructure—across advanced, transitional, and developing economies. For the purposes of the graphical representation, the proportion of internet users was normalized by multiplying the share values by 10 000, thereby converting them into percentage points consistent with the econometric specification and ensuring comparability across clusters. The econometric interpretation of these indicators highlights the structural heterogeneity among clusters.

Advanced economies exhibit high GDP per capita, near-universal internet penetration, and extensive security infrastructure. This alignment confirms the regression results: technological diffusion (β_1) and institutional safeguards (β_2) are mutually reinforcing, producing strong complementarities (β_3). The graphical dominance of these indicators illustrates how digital maturity and institutional robustness translate into sustained growth.

Transitional economies occupy an intermediate position. GDP per capita and internet penetration are moderate, while secure servers show significant variation. The chart

reflects the econometric finding that the interaction term is particularly relevant here. The visual gap between digital access and institutional safeguards underscores the policy challenge: convergence requires simultaneous strengthening of both dimensions.

Developing economies are positioned at the lower end of all three indicators. The chart confirms the regression evidence that elasticities are smaller but positive. Even modest improvements in internet penetration or security infrastructure can shift the trajectory upward. The graphical representation of low but rising values illustrates the potential for incremental transformation.

From an econometric perspective, the chart validates the statistical inference: ANOVA confirms significant heterogeneity across clusters, while regression coefficients quantify the elasticities. The visualization thus bridges statistical outcomes with structural realities, making the disparities and complementarities tangible for the audience.

5.3 Policy Implications by Country Group

The empirical findings of this study carry significant implications for economic policy, institutional design, and long-term development strategies. By demonstrating that technological diffusion and institutional safeguards function as complementary pillars of growth, the analysis provides a clear framework for policymakers across different clusters of economies. The results show that neither digital expansion nor institutional strengthening alone is sufficient; only their co-evolution produces durable and resilient growth trajectories.

Advanced Economies For advanced economies, the policy challenge is consolidation rather than expansion. These countries already possess mature digital ecosystems and robust institutional frameworks. The priority is to ensure that these systems remain adaptive, secure, and globally competitive. This requires continuous investment in frontier innovation, such as artificial intelligence, quantum computing, and next-generation ICT infrastructure. At the same time, governance frameworks must evolve to address new risks, particularly those related to cybersecurity and systemic vulnerabilities in digital networks. Institutional mechanisms that safeguard against cyber shocks, data breaches, and algorithmic biases are essential to maintain trust and resilience. Advanced economies must also focus on sustaining innovation capacity by investing in human capital, promoting lifelong learning, and embedding digital literacy across all levels of society. In this way, they can preserve their leadership in global value chains and ensure that productivity growth remains robust in the long run.

Transitional Economies For transitional economies, the findings highlight the importance of synchronized policy sequencing. Moderate elasticities combined with strong interaction effects suggest that convergence potential lies in simultaneous investment in ICT adoption and institutional strengthening. Policy interventions should therefore prioritize dual strategies: expanding digital access while embedding regulatory and security frameworks. This dual orientation accelerates structural transformation, narrows the income gap with advanced economies, and enhances resilience against volatility. Transitional economies stand at a critical juncture where complementarities between digital and institutional dimensions can catalyze convergence. Policymakers must avoid the trap of focusing exclusively on infrastructure without addressing institutional credibility, or vice versa. Diplomatic alignment with supranational frameworks, such as European integration processes, provides both legitimacy and access to structural support, reinforcing institutional capacity and accelerating convergence. The strategic imperative is clear: transitional economies must pursue balanced development strategies that integrate digital expansion with institutional robustness.

Developing Economies For developing economies, the policy message is one of foundational sequencing. Lower elasticities reflect structural constraints such as limited infrastructure, low penetration rates, and weak institutional safeguards. Yet the positive coefficients confirm that even incremental improvements yield meaningful gains. Policy should therefore focus on basic measures: expanding affordable internet access, building essential ICT infrastructure, and establishing minimal institutional safeguards to foster trust in digital transactions. These steps initiate upward trajectories and create conditions for future complementarities. The sequencing of reforms is crucial: digital foundations must be laid first, followed by gradual strengthening of institutional capacity. This ensures that growth is inclusive, durable, and capable of absorbing the benefits of digitalization. Developing economies must also invest in human capital, promoting digital literacy and skills development to enhance absorptive capacity. By doing so, they can transform digitalization into a genuine driver of structural change and long-term convergence.

Cross-Cluster Lessons Across all clusters, the study demonstrates that technological diffusion without institutional safeguards remains fragile, while institutional safeguards without digital transformation are insufficient. Only their combination produces durable and dynamic growth channels. Advanced economies exemplify the maturity of this synergy, transitional economies highlight its potential for accelerated convergence, and developing economies reveal the transformative promise of foundational sequencing.

The insights derived from this study point toward a set of strategic directions that are essential for embedding digital transformation within sustainable development. At the core lies the recognition that digital expansion and institutional strengthening are not parallel but interdependent processes. Governments must therefore adopt integrated policy designs that treat these dimensions as complementary, ensuring that investments in ICT infrastructure are matched by reforms that enhance institutional credibility and resilience.

Human capital emerges as a decisive factor in this equation. Digital literacy, skills development, and lifelong learning are not ancillary but central to enabling societies to fully absorb and benefit from technological diffusion. Without a population equipped to navigate and utilize digital tools, the productivity gains associated with technological adoption remain limited.

Equally critical is the dimension of trust. Cybersecurity frameworks and secure digital infrastructure are indispensable for safeguarding the credibility of digital economies. In an era where vulnerabilities can undermine systemic stability, institutional mechanisms that protect against cyber risks are fundamental to sustaining confidence and resilience.

International alignment further strengthens this trajectory. Engagement with supranational frameworks and adherence to international standards provide not only credibility but also access to resources and knowledge networks that accelerate convergence. Such alignment situates national strategies within a broader global architecture, reinforcing legitimacy and facilitating structural transformation.

Sequencing of reforms is particularly relevant for developing economies. Building digital foundations must precede the establishment of complex institutional frameworks, ensuring that progress is both inclusive and durable. By laying the groundwork through affordable access and basic infrastructure, these economies create the conditions for future complementarities between technology and institutions.

These recommendations articulate a coherent policy vision: digitalization becomes a genuine driver of inclusive and resilient growth only when anchored in institutional robustness. The strategic imperative is to integrate, invest, safeguard, align, and sequence reforms in a manner that reflects the structural realities of each cluster of economies. In

doing so, policymakers can transform digital transformation from a statistical correlation into a structural determinant of long-term prosperity.

6. CONCLUSION

The empirical analysis provides robust evidence that income disparities across heterogeneous clusters of economies are systematically determined by the dual forces of technological diffusion and institutional safeguards. This finding situates itself within the broader econometric literature on convergence, where growth trajectories are shaped not only by capital accumulation but also by absorptive capacity and institutional credibility.

From a statistical standpoint, the robustness of the results is confirmed through strong inferential diagnostics, including significant t-statistics, low p-values, and ANOVA tests that validate structural heterogeneity across clusters. Variance decomposition further indicates that institutional quality explains a substantial share of inter-cluster disparities, while technological diffusion accounts for intra-cluster variation. This duality underscores the econometric truth that development outcomes are embedded in both digital access and institutional resilience.

Economically, the implications are profound. Advanced economies demonstrate the dividends of sustained complementarities, where mature digital ecosystems and robust institutions generate long-term productivity gains and resilience against external shocks. Transitional economies reveal the critical importance of synchronizing ICT adoption with institutional strengthening, as convergence potential depends on the co-evolution of these dimensions. Developing economies, despite structural constraints, show that even incremental improvements in connectivity and institutional safeguards can yield meaningful upward shifts in growth trajectories.

Theoretically, these findings align with endogenous growth models, where human capital, innovation, and institutional quality interact to produce non-linear convergence dynamics. The evidence confirms that technological diffusion without institutional safeguards leads to fragile growth, while institutional safeguards without digital transformation result in stagnation. Only their synergy produces durable and dynamic growth channels, positioning the digital-institutional nexus as a structural determinant of long-term development.

In broader policy terms, the study reinforces a central message: strategies that integrate digital expansion with institutional robustness are more effective than isolated interventions. Advanced economies exemplify the maturity of this synergy, transitional economies highlight its potential for accelerated convergence, and developing economies reveal its transformative promise. By embedding empirical evidence within a rigorous econometric framework, the study contributes to the scientific understanding of structural drivers of income disparities and offers a replicable methodology for future research. Ultimately, the conclusion is clear—digitalization becomes a genuine driver of inclusive, resilient, and sustainable growth only when anchored in institutional credibility.

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