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Digital Catalysts: SEM Analysis of Technological Infrastructure, Entrepreneurial Ecosystems, and Economic Productivity using World Bank Data

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***Abstract**. The transition from investment-driven to innovation-driven economies places technological infrastructure at the forefront of macroeconomic development. This study utilizes Structural Equation Modeling (SEM) to analyze the complex causal relationships between technological infrastructure, the entrepreneurial ecosystem, and economic productivity across 179 economies using comprehensive World Bank data. Grounded in Endogenous Growth Theory, we hypothesize that digital infrastructure serves as a critical catalyst for entrepreneurship, which in turn drives higher economic value added and industrial output. To ensure methodological robustness, the study employs a rigorous data pre-processing approach, specifically transforming skewed variables—such as secure internet servers, patent counts, and trademark applications—into their natural logarithms (Ln) to satisfy distributional normality assumptions for linear modeling. Results derived from Jamovi analysis indicate that technological readiness significantly influences entrepreneurial capacity, which acts as a key mediator subsequently impacting GDP per person employed and industrial value added. These empirical findings suggest that policymakers must prioritize strategic digital backbone investments and secure server infrastructure to unlock the full potential of national entrepreneurial ecosystems. By bridging the digital divide, nations can foster an environment conducive to sustainable innovation and long-term economic growth.*

***Keywords**: Economic Productivity; Entrepreneurial Ecosystem; Logarithmic Transformation; Structural Equation Modeling; World Bank Data.*

1. INTRODUCTION

The contemporary global economy is increasingly defined by the digital paradigm, where the integration of Artificial Intelligence (AI) and robust digital infrastructure is reshaping national accounts and productivity metrics (Mohamed et al., 2026). As nations transition into digitalized economies, traditional methods of measuring GDP and economic performance must adapt to capture the value generated by digital inputs (Ahmad & Schreyer, 2016). Furthermore, recent studies emphasize that the digital economy is inextricably linked to broader global goals, including environmental sustainability and cross-country coordination (Liu & others, 2024). Unlike traditional neoclassical models that view technology as an exogenous factor, Endogenous Growth Theory posits that technological advancements and knowledge accumulation are internal drivers of economic systems (Ullah et al., 2018; World Bank, 2024b). In this context, the "digital divide" represents not merely a gap in access but a fundamental divergence in economic potential and entrepreneurial capacity.

Despite the proliferation of digital tools, the mechanisms by which infrastructure translates into tangible economic productivity remain complex. The World Bank's Digital Progress and Trends Report (World Bank, 2025) highlights that while digital sectors are growing twice as fast as the global economy, the productivity gap between advanced and

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emerging economies persists. This paper addresses this gap by employing Structural Equation Modeling (SEM) to deconstruct the pathways between technological inputs (broadband, secure servers, high-tech exports) and economic outputs (GDP per employee, patents), mediated by the entrepreneurial ecosystem.

Specific attention is paid to the distributional characteristics of global economic data. As noted in methodological handbooks (World Bank, 2024a), indicators such as intellectual property applications and server density exhibit high skewness, necessitating logarithmic transformations to satisfy the normality assumptions of SEM.

2. THEORETICAL REVIEW

Technological Infrastructure and Economic Growth

Digital infrastructure is the backbone of the modern economy. Studies indicate that fixed broadband subscriptions and secure internet servers are critical determinants of corporate investment efficiency and regional growth (Wang et al., 2025). The availability of high-speed internet reduces transaction costs and facilitates the diffusion of knowledge, which is essential for "catch-up" growth in middle-income countries (World Bank, 2024b). Furthermore, high-technology exports serve as a proxy for a nation's ability to internalize and commercialize complex technical knowledge (Colovic & Lamotte, 2015).

The Entrepreneurial Ecosystem

The concept of the entrepreneurial ecosystem extends beyond the individual firm to include the broader institutional and physical environment (Firman et al., 2024). Developing a robust diagnostic toolkit for these ecosystems is essential for identifying bottlenecks in digital business formation (Zhu & Cruz, 2023). Furthermore, the transition toward a more "Business Ready" (B-READY) environment underscores the necessity of high-quality regulations and physical infrastructure to support private sector development (Loayza & Perotti, 2026). Access to domestic credit and the protection of intellectual property (trademarks) are foundational elements that allow latent entrepreneurial talent to manifest as formal business activities (Klapper et al., 2008). (Constand & Gilbert Jr., 2011) argue that "e-readiness" is a significant predictor of early-stage entrepreneurial activity, suggesting a strong link between the technological environment and business formation.

Theoretical Framework

Drawing on Endogenous Growth Theory, we propose a structural model where:

a. TECH (Exogenous): Represents digital maturity.
b. ENT (Mediator): Represents the vibrancy of the private sector and innovation protection.
c. PROD (Endogenous): Represents labor productivity and industrial output.

3. RESEARCH METHODS

Data Source and Variables

Data for this study were sourced from the World Bank's World Development Indicators (WDI) and the (World Intellectual Property Organization, 2024). The dataset covers 179 economies. The variables used are detailed in Table 1.

Table 1. Variable Definitions and Sources.

Code	Indicator Name	Source Note
IT.NET.SECR.P6	Secure Internet servers (per 1 million people)	The number of distinct, publicly-trusted TLS/SSL certificates found in the (Netcraft, 2024) Secure Server Survey.
IT.NET.BBND.P2	Fixed broadband subscriptions (per 100 people)	Subscriptions to high-speed access to the public Internet (≥ 256 kbit/s), including cable, DSL, fiber, etc. (International Telecommunication Union, 2024).
TX.VAL.TECH.MF.ZS	High-technology exports (% of manufactured exports)	Products with high R&D intensity, such as aerospace, computers, pharmaceuticals, and scientific instruments ((United Nations, 2024)).
FS.AST.PRVT.GD.ZS	Domestic credit to private sector (% of GDP)	Financial resources provided to the private sector by financial corporations, such as loans and trade credits (IMF/World Bank).
IP.TMK.RSCT	Trademark applications, resident, by count	Applications filed with the IP office of the state in which the first named applicant is resident (World Intellectual Property Organization, 2024).
SL.GDP.PCAP.EM.KD	GDP per person employed (constant 2021 PPP $)	GDP divided by total employment. Converted to 2021 constant international dollars using PPP rates ((International Labour Organization, 2024)).
IP.PAT.RESD	Patent applications, residents	Worldwide patent applications filed through the Patent Cooperation Treaty or national offices (World Intellectual Property Organization, 2024).

NV.IND.TOTL.ZS	Industry (including construction), value added (% of GDP)	Value added in mining, manufacturing, construction, electricity, water, and gas industries ((OECD, 2025)).

Data Pre-processing: Logarithmic Transformation

A critical step in this analysis was addressing the non-normal distribution of several key variables. Economic data involving "pure counts" or monetary values often exhibit severe right-skewness, where a few leading economies drive the mean far above the median (Sadenova et al., 2025). To stabilize variance and satisfy the normality assumption of Maximum Likelihood (ML) estimation in SEM, we applied Natural Logarithm (Ln) transformations.

The following transformations were performed using the Excel formula =LN(Cell) or =LN(Cell + 1)for variables containing zeros:

a. Ln_SecureServers: Transformation of IT.NET.SECR.P6. Secure server counts can range from single digits in developing nations to millions in advanced economies.
b. Ln_Trademarks: Transformation of IP.TMK.RSCT. Trademark applications exhibit a wide range and high variance.
c. Ln_GDPProd: Transformation of SL.GDP.PCAP.EM.KD. Standard econometric practice dictates using log-GDP to interpret changes in percentage terms (elasticity).
d. Ln_Patents: Transformation of IP.PAT.RESD. Patent data is notoriously skewed, with a high concentration in a few innovation hubs.

Analytic Strategy

The analysis was conducted using the jmv (Jamovi) module for Structural Equation Modeling. The model specification is as follows:

1) Latent Factor TECH: Loaded by Ln_SecureServers, IT.NET.BBND.P2, and TX.VAL.TECH.MF.ZS.
2) Latent Factor ENT: Loaded by FS.AST.PRVT.GD.ZS and Ln_Trademarks.
3) Latent Factor PROD: Loaded by Ln_GDPProd, Ln_Patents, and NV.IND.TOTL.ZS.

4. RESULTS AND DISCUSSION

Descriptive Statistics

The dataset comprises 179 observations. Following the transformation, variables such as Ln_SecureServers and Ln_GDPProd showed improved distributional characteristics suitable for linear modeling. The intercepts derived from the analysis (e.g., Ln_SecureServers ≈ 6.79; IT.NET.BBND.P2 ≈ 16.41) provide a baseline for the global average in the transformed space.

Model Fit and Structural Analysis

The Structural Equation Model was estimated using the Maximum Likelihood (ML) method with NLMINB optimization. The model converged after 195 iterations. The overall model fit yielded a χ^2 value of 178 with 17 degrees of freedom ($p < .001$). While the significant chi-square suggests some deviation between the model and observed covariance matrices—a common occurrence in large macroeconomic datasets—the structural paths provide valuable insights.

Structural Path Estimates: The analysis posits the following relationships:

a. TECH → ENT: The path from Technological Infrastructure to the Entrepreneurial Ecosystem is significant. This confirms that access to secure servers and broadband is a prerequisite for modern business formation and credit utilization.
b. ENT → PROD: The Entrepreneurial Ecosystem significantly predicts Productivity. Economies with higher trademark activity and private sector credit generates higher value-added per employee.
c. TECH → PROD: There is a direct structural link between technology and productivity, supporting the thesis that digital tools directly enhance industrial efficiency beyond just facilitating business entry.

Note on Estimation: The analysis flagged that some observed variances were significantly larger than others (scaling factor > 1000), validating the decision to use Logarithmic transformations for variables like GDP and Patent counts to mitigate numerical instability during estimation.

Discussion

The findings of this study reinforce the "Digital Catalyst" hypothesis. The strong loading of Ln_SecureServers on the TECH factor suggests that trust and security in digital transactions are just as physical connectivity (IT.NET.BBND.P2) for economic development. This aligns with the Digital Progress and Trends Report (World Bank, 2025), which emphasizes that connectivity alone is insufficient without secure foundations. The mediation role of the ENT factor highlights that technology requires a conducive business environment to translate into productivity (Zhu & Cruz, 2023). This includes maintaining a business-ready atmosphere that balances regulation with firm autonomy (Loayza & Perotti, 2026).

The mediation role of the Entrepreneurial Ecosystem (ENT) highlights that technology requires a conducive business environment to translate into productivity. As noted by (Klapper et al., 2008), firm formation is sensitive to the regulatory and financial environment. Our model confirms that when technology is paired with financial depth (FS.AST.PRVT.GD.ZS) and intellectual property protection (Ln_Trademarks), the impact on GDP per capita (Ln_GDPProd) is amplified.

However, challenges regarding endogeneity remain. As discussed by (Ullah et al., 2018), the causal loop between growth and investment is complex; wealthy nations invest more in tech, which causes more growth. While SEM helps disentangle these paths, future research could employ Generalized Method of Moments (GMM) to further control for reverse causality in panel data settings.

5. CONCLUSION AND SUGGESTIONS

This paper utilized Structural Equation Modeling on World Bank data to demonstrate the critical role of technological infrastructure in accelerating economic productivity. By strictly applying logarithmic transformations to skewed variables such as Secure Servers and Patents, we achieved a more robust analysis of global economic disparities.

The results suggest that development policies should not operate in silos. Investments in broadband and secure servers must be accompanied by reforms that strengthen the private credit market and intellectual property regimes. Only through this holistic "ecosystem" approach can emerging economies bridge the productivity gap and transition toward high-value-added industrial activities.

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