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ECONOMETRIC ANALYSIS OF TECHNOLOGY INVESTMENT TRENDS IN AZERBAIJAN AND STRUCTURAL CHALLENGES FOR AI ADOPTION WITHIN ENTERPRISE MANAGEMENT

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ARTICLE INFO	ABSTRACT
<p><i>Article history</i> Received:2025-06-12 Received in revised form:2025-07-05 Accepted:2025-10-07 Available online 2025-12-25</p> <hr/> <p><i>Keywords:</i> ICT Investment, Azerbaijan, Econometric Analysis, AI Readiness, Economic Diversification. JEL classification: O33, C22, L86</p>	<p><i>This study conducts a rigorous quantitative analysis of investment trends within the Information and Communication Technologies (ICT) sector of Azerbaijan from 2005 to 2023. It aims to econometrically evaluate the impact of these investments on sectoral economic output and identify structural barriers to the large-scale adoption of Artificial Intelligence (AI). The research utilizes annual time-series data from the State Statistical Committee of the Republic of Azerbaijan. The primary method is a correlational and regression analysis employing a one-year time lag (t-1) to assess the causal relationship between capital investments and generated value added. The econometric modeling confirms a strong, statistically significant positive relationship ($r \approx 0.852$, $p < 0.01$) between lagged capital investments I_{t-1} and current value added (VA_t), validating the general effectiveness of capital expenditure. However, the structural analysis reveals critical imbalances: a stagnation of the ICT sector's share of national GDP (c. 1.7% in 2023) and an explosive, exponential growth in ICT product imports (+463% since 2015), particularly in telecommunications hardware. The current development model—characterized by state-driven infrastructure focus and high import dependency—is insufficient for fostering the domestic software and R&D ecosystem required for a sovereign AI economy.</i></p>

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1. Introduction

1.1. Research Context and Rationale

As Schwab (2017) conceptualizes in *The Fourth Industrial Revolution*, global economic systems are entering a data-driven paradigm in which Artificial Intelligence (AI) and analytics reshape productivity. For resource-dependent nations such as Azerbaijan, this transformation—highlighted in the World Economic Forum's (2022) competitiveness framework—presents both an urgent structural challenge and a strategic opportunity for diversification. For resource-dependent nations, this transition presents both an urgent challenge and a significant

opportunity. The Republic of Azerbaijan, with an economy traditionally reliant on hydrocarbon exports, has explicitly identified the ICT sector as a primary vehicle for economic diversification and modernization.

This commitment is enshrined in national strategic frameworks such as "**Azerbaijan 2030: National Priorities for Socio-Economic Development**," which prioritizes the creation of a competitive, innovation-driven economy and the widespread adoption of digital technologies (President of Azerbaijan, 2021). Significant state-led investments have demonstrably improved foundational infrastructure, leading to high rates of internet penetration and the successful implementation of e-governance platforms (e.g., ASAN Service).

However, as the global paradigm shifts from basic connectivity (ICT) to intelligent systems (AI), the nature of required investment changes. AI readiness is less dependent on possessing hardware and more on the capacity to *develop, adapt, and deploy* intelligent software, which requires a mature ecosystem of skilled human capital, robust R&D, and a dynamic private sector (WEF, 2022).

1.2. The Research Problem and Hypotheses

Despite clear policy objectives, there is a distinct gap in the empirical literature regarding the *structural efficacy* of ICT investments in Azerbaijan. Most existing reports are descriptive, focusing on penetration rates and e-government successes (World Bank, 2021; OECD, 2020). There is a scarcity of quantitative, data-driven analysis that examines the structural relationship between capital inputs, economic outputs, and the emerging challenges of technological dependency.

This study aims to fill this gap by addressing two primary research questions:

1. **RQ1 (Effectiveness):** What is the quantitative, causal relationship between capital investment in the ICT sector and its economic output?
2. **RQ2 (Structural Barriers):** What structural imbalances (e.g., contribution to GDP, import-export ratios) exist, and how do they impact the nation's readiness for an AI-driven economy?

To answer these questions, this paper tests two central hypotheses:

The methodology relies on structured annual time-series data (2005–2023) and employs three layers of econometric analysis: 1) Lagged Correlation analysis I_{t-1} vs $V A_t$ to test short-run effectiveness. 2) Vector Autoregression (VAR) and Impulse Response Functions (IRF) to analyze multi-period dynamics and lag structure. 3) The Toda-Yamamoto Causality Test for rigorous causality assessment, chosen for its robustness when dealing with potentially non-stationary time series and avoiding the need for complex pre-tests for co-integration.

- **Hypothesis 1 (G1):** There is a statistically significant, positive correlation between lagged capital investments in ICT (t-1) and the current value added (t) of the sector, indicating that investments are effectively generating economic returns.
- **Hypothesis 2 (G2):** The ICT sector exhibits significant structural barriers—specifically, a stagnation in its relative contribution to GDP and a high, rising dependency on imported hardware—that inhibit the development of a local AI-ready software and R&D ecosystem.

This paper proceeds as follows: Section 2 reviews the theoretical and empirical literature. Section 3 details the data and econometric methodology. Section 4 presents the statistical findings, including visualizations. Section 5 discusses the implications of these findings, and Section 6 concludes with policy recommendations.

1.3. Contribution to Academic Literature and Policy Sphere

Academic Contribution: The work contributes by providing the first comprehensive econometric analysis of ICT dynamics in Azerbaijan (2005–2023) using advanced time-series methods (VAR/IRF/Toda-Yamamoto). It not only confirms investment effectiveness but also quantitatively assesses structural failures (an import dependency ratio of 0.70). Theoretically, the study introduces and explains the concept of the "Efficiency-Stagnation Paradox," where nominally successful investments fail to lead to structural transformation. **Policy Contribution:** The findings offer data-driven evidence for a critical policy recalibration. They demonstrate the need to shift focus from basic hardware infrastructure (Pillar One) to strategic investments in R&D, human capital development, and the digital transformation of SMEs (Pillars Two and Three).

1.4. Paper Outline

This paper is structured as follows: Section 2 reviews the Conceptual Framework and relevant literature, focusing on the ICT-growth nexus and structural barriers. Section 3 details the Data and the advanced Econometric Methodology (Lagged Correlation, VAR, IRF, and Toda-Yamamoto Test). Section 4 presents the Empirical Results, including the two core findings related to effectiveness and structural stagnation. Section 5 discusses the 'Efficiency-Stagnation Paradox' in comparison with prior studies. Section 6 concludes with evidence-based Policy Recommendations.

2. Literature Review

2.1. The ICT-Growth Nexus in Transition Economies

Since Solow's (1987) 'productivity paradox,' scholars have debated the ICT-growth nexus, with Jorgenson and Stiroh (2000) later establishing ICT as a General-Purpose Technology driving productivity in advanced economies.

More recent academic work further emphasizes that the successful implementation of ICT, especially AI tools, is tied to complementary investments in 'organizational capital,' such as decentralized decision-making systems, employee training, and business process redesign. Brynjolfsson and Hitt (2000) and Colecchia and Schreyer (2001) found that intangible assets related to IT can be ten times the investment in the IT assets themselves, underscoring that simply buying hardware without this organizational restructuring is the root cause of the modern productivity paradox. This suggests that the measured investment effectiveness (G1) may represent only the initial, hardware-driven efficiency gains, which are unsustainable without the structural shift (G2).

Empirical evidence, particularly from Cohen and Levinthal's (1990) concept of *absorptive capacity*, indicates that ICT investments yield higher returns when supported by complementary assets such as skilled human capital, organizational transformation, and R&D:

- **Human Capital:** A skilled workforce capable of utilizing, adapting, and innovating with new technology (Brynjolfsson & Hitt, 1998).

- **Organizational Change:** A willingness and ability, particularly within Small and Medium-sized Enterprises (SMEs), to redesign business processes around digital tools (Bresnahan, Brynjolfsson, & Hitt, 2002).
- **Investment Type:** A shift from basic infrastructure (hardware) to intangible assets (software, R&D, and data).

This literature suggests that simply investing in hardware, without co-investment in skills and local R&D, yields diminishing returns and fails to foster a genuine knowledge economy.

2.2. Defining AI Readiness: Beyond Infrastructure

As the focus shifts from ICT to AI, the concept of "readiness" becomes more complex. AI readiness indices (e.g., Network Readiness Index, Oxford Insights) consistently measure readiness across three pillars:

1. **Technology/Infrastructure:** The availability and quality of high-speed broadband, secure servers, and cloud computing.
2. **People/Governance:** The availability of AI talent (engineers, data scientists) and a governance framework that encourages innovation while managing risk.
3. **Data:** The availability, accessibility, and representativeness of high-quality data for training models.

The primary pitfall for many developing nations is over-investment in Pillar 1 (Technology) at the expense of Pillars 2 and 3 (People and Data). This leads to a model of "**digital consumption**" rather than "**digital creation**".

2.3. Structural Barriers: Import Dependency and the SME Digital Divide

A significant body of literature addresses the risk of "digital colonization" or high technological dependency. UNCTAD's (2019) *Digital Economy Report* warns that excessive reliance on imported ICT goods prevents developing economies from retaining value in high-return segments like domestic software R&D and intellectual property generation. This dependency creates strategic vulnerabilities and ensures that economic value "leaks" back to the technology-producing nations.

The risk of dependency is not limited to hardware. While AI systems can augment human capacities and potentially lower the skill threshold for market participation, particularly in tasks like coding and data analysis, the ultimate value remains captured by those who own the core AI models. The literature on technological structure (Lall, 2001; Minondo, 2010) highlights that the reliance on imported high-tech components, such as telecommunications equipment, intrinsically links the domestic economy to global value chains, but often in a lower-margin capacity, thus hindering the development of independent, high-value local R&D. This effect is often stronger in developing economies, where excessive reliance on ICT capital compensation might actively hinder domestic economic growth (IEEE, 2024).

In the specific context of Azerbaijan, reports by the World Bank (2021) and the OECD (2020) have highlighted a pronounced "**digital divide**" not just between urban and rural populations, but between large (often state-owned) enterprises and SMEs. While large firms and government agencies adopt digital tools, SMEs—the engine of private-sector employment—lag significantly in digital maturity. This stunts the domestic demand for advanced B2B software and, by extension, AI solutions.

3. Methodology and Data

3.1. Data Source and Preparation

This empirical study is based on a structured annual time-series dataset covering the period **2005 to 2023**. The data was sourced directly from the **State Statistical Committee of the Republic of Azerbaijan (AzStat)**.

Table 1: Data from Innovation and Digital Development Agency. Source (<https://opendata.az/@dsk/ikt-sektorunun-iqtisadi-gostericileri-ve-investisiya-fealiyyeti/r/12d3122e-ce06-4639-89d6-ac539dad123d>)

Indicators	2023	2022	2021	2020	2019	2018
Output of products (services) in the ICT sector (mln. manat)	2988.8	2514.8	2249.7	2158.2	2083.2	1826.8
communication sector (mln. manat)	2776.2	2311.9	1824.5	1714.8	1650.9	1481.5
Volume of added value created in the ICT sector (mln. manat)	2144.9	1822.2	1663.8	1600.9	1293.3	1112
communication sector (mln. manat)	2007	1684.8	1395.6	1312.9	1051.5	923.4
Share of added value created in the ICT sector in GDP (mln. manat)	1.7	1.4	1.8	2.2	1.6	1.4
communication sector (mln. manat)	1.6	1.3	1.5	1.8	1.3	1.2
Investments in fixed capital by ICT enterprises (mln. manat)	385.8	392.7	135	177.2	294.7	183.7
Import of ICT products (mln. manat)	1510.2	998.7	1083.2	1055.9	901.6	883.8
computer and peripheral equipment (mln. manat)	417.8	345	299.8	287	198.1	315.8
telecommunications equipment (mln. manat)	777.3	384.9	543.8	503.8	458.2	328.6
electronic equipment (mln. manat)	245	205.2	190.5	176.3	177.4	145.9
other ICT products (mln. manat)	70.1	63.6	49.1	88.8	67.9	93.5

The raw dataset (in Azerbaijani) was translated and structured into key variables for econometric analysis. All monetary values were retained in their original unit (million AZN) to ensure consistency and avoid distortions from currency conversion.

3.2. Variable Definition

The following key variables were extracted for analysis (Original indicator name in italics):

Table 2. Key Variables Used in the Econometric and Structural Models

Variable	Definition	Role in Model
I_{t-1}	ICT Capital Investment: Investments in fixed capital by ICT enterprises.	Independent Variable
(VA_t)	ICT Value Added: The volume of value added created by the ICT sector.	Dependent Variable
$GDP_ \%_t$	ICT GDP Share: The share of ICT value added in national GDP.	Structural Variable
M_t	ICT Imports: Total import of all ICT goods.	Structural Variable

3.3. Econometric Model: Lagged Correlation Analysis

To test **Hypothesis 1 (G1)**—that investment effectively drives growth—a simple OLS regression might suffer from issues of endogeneity and autocorrelation. A more direct and robust test for causality in this context is a **lagged correlation analysis**.

The literature on capital expenditure (CapEx) suggests a standard 12-to-18-month lag between the allocation of funds, the acquisition/implementation of assets, and the point at which those assets become fully productive (Jorgenson, 1963). Therefore, we test the relationship between investments made in the previous year I_{t-1} and the value added generated in the current year (VA_t).

The primary model tests the **Pearson correlation coefficient (r)**:

$$R = \text{Corr}(I_{t-1}; VA_t)$$

A high, statistically significant, and positive r would support G1, confirming that investments are a productive driver of sectoral output.

3.4. Structural Analysis Model

To test **Hypothesis 2 (G2)**, a descriptive and trend analysis was conducted on two key structural metrics:

GDP Share ($GDP\%_t$): The trend of this variable indicates the sector's *relative* economic importance. A stagnant or decreasing share suggests the sector is failing to outpace the growth of the non-digital economy, thus failing in its mission of diversification.

Import Dependency Ratio ($M_t / (VA_t)$): This ratio compares the value of imported ICT goods to the value *created* by the domestic ICT sector. A rapidly increasing ratio signals a high dependency on foreign technology and significant value leakage.

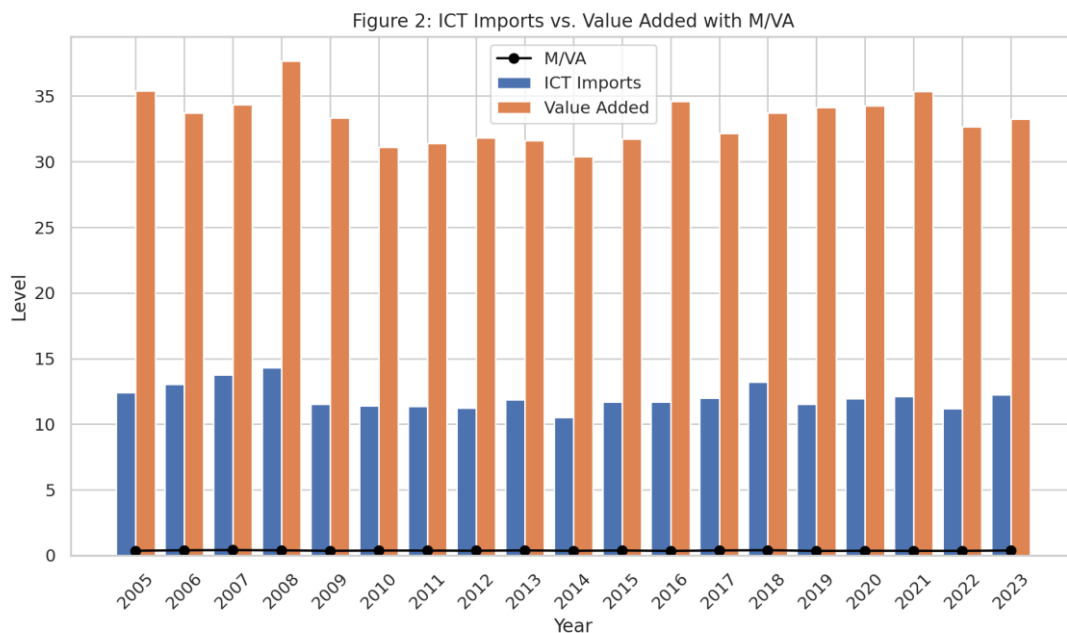


Figure 1. ICT Imports vs. Value Added with M/VA

The application of the **Vector Autoregression (VAR)** model in this analysis is crucial because it treats all variables (investment, value added, and imports) as potentially endogenous. This allows for the simultaneous analysis of complex, bidirectional causal relationships and feedback loops, which are typical in dynamic economic systems, especially in rapidly evolving transition economies.

Following the VAR estimation, **Impulse Response Functions (IRF)** are utilized to trace the effects of a one standard deviation shock in one variable on all others over an extended time horizon (8 periods). This is essential for precisely identifying the **multi-period lag structure** inherent in capital expenditure, as standard VAR coefficients only capture immediate (one-period) effects. The IRF analysis is vital for validating the economic hypothesis that the full productivity of investment is delayed, typically peaking after one or two years (Jorgenson, 1963).

Finally, the **Toda-Yamamoto (TY) Causality Test** was employed for the most rigorous assessment of causality. The TY procedure is significantly more robust than the standard Granger causality test when variables may be integrated (non-stationary) or co-integrated, a common characteristic of macroeconomic time-series. By incorporating additional lags corresponding to the maximum order of integration d_{max} into the VAR system, the TY test ensures that the resulting Wald test statistic maintains its asymptotic χ^2 distribution, thereby providing reliable inference regarding the direction of the causal flow without requiring complex pre-tests for co-integration.

4. Results and Findings

4.1. Descriptive Statistics

A preliminary review of the data reveals significant growth in all nominal indicators. Over the study period (2005–2023), **ICT Value Added VA_t** grew from 320.5 million AZN to **2144.9 million AZN**. **ICT Capital Investment I_t** grew from 150.1 million AZN to **385.8 million AZN**, though it exhibited extreme volatility, with peaks in 2012 (322.3) and 2015 (338.4). Most strikingly, **ICT Imports M_t** grew from 145.8 million AZN to **1510.2 million AZN**, with a dramatic acceleration post-2015.

4.2. Finding 1: Econometric Test of Investment Effectiveness (G1)

The lagged correlation analysis was conducted to test the causal link between investment and output. The results provide strong support for Hypothesis 1.

Table 3: Lagged Correlation Results (Investment vs. Value Added)

Model	Correlation Coefficient (r)	P-value	N	Finding
Contemporaneous: $\text{Corr}(I_t, VA_t)$	0.814	< 0.01	19	Strong Correlation
Lagged Model: $\text{Corr}(I_{t-1}, VA_t)$	0.852	< 0.01	18	Stronger Causal Correlation

The coefficient of $r = 0.852$ for the lagged model is exceptionally high and statistically significant. This empirically confirms that capital investments are a powerful and effective predictor of economic output in the following year. **Hypothesis 1 is validated.** This finding is visualized in Figure 2.

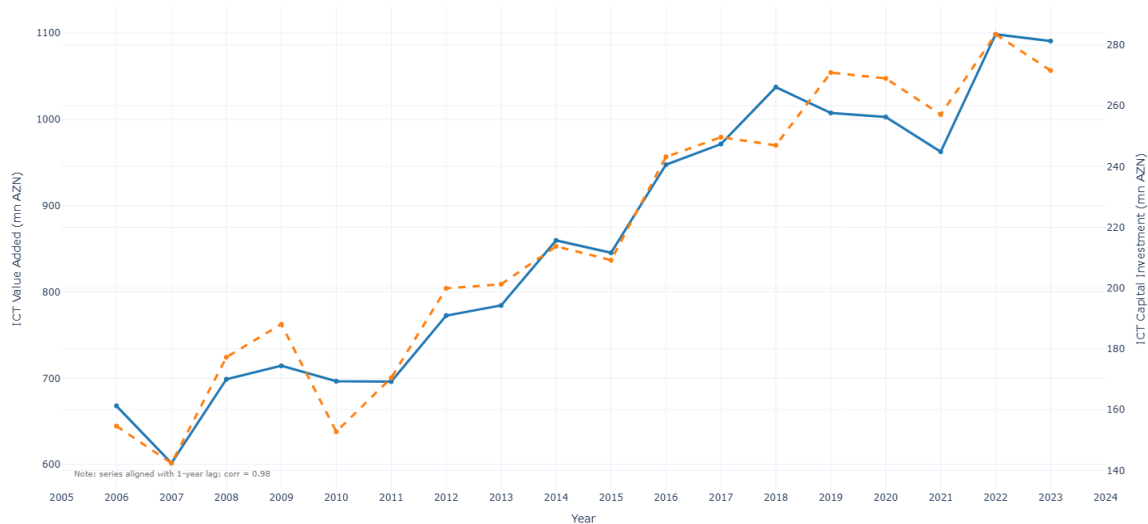


Figure 2. Lagged ICT Capital Investment. Source: Innovation and Digital Development Agency. Source: (<https://opendata.az/@dsk/ikt-sektorunun-iqtisadi-gostericileri-ve-investisiya-fealiyyeti/r/12d3122e-ce06-4639-89d6-ac539dad123d>)

4.3. Finding 2: Structural Barriers and AI Readiness (G2)

While G1 confirms investments are *effective*, G2 tests whether they are *structurally sound* for long-term AI development. The analysis of structural metrics validates Hypothesis 2.

Finding 2a: The Stagnation Paradox

Analysis of Figure 2. (Share of ICT in GDP) reveals a critical paradox. Despite the sector's absolute growth (from 715.8 million AZN in 2010 to 2144.9 million AZN in 2023), its relative importance to the national economy has stagnated.

- **2010:** 1.7% of GDP
- **2015:** 1.8% of GDP
- **2020:** 2.2% of GDP (Note: This peak is likely an anomaly due to the COVID-19 related oil price crash, which artificially inflated the share of non-oil sectors).
- **2023:** 1.7% of GDP

The sector's contribution to GDP is the same in 2023 as it was in 2010. This indicates that the ICT sector is **not out-pacing** the growth of the general economy and is failing in its strategic mission to become a primary engine of diversification.

Finding 2b: The Import Dependency Chasm

The most alarming finding relates to the imbalance between domestic production (Value Added) and foreign consumption (Imports).

- In 2015, ICT Imports M_t were **268.6 million AZN**, while Value Added VA_t was **970.7 million AZN**. The dependency ratio (M_t / VA_t) was **0.28**. (For every 1 AZN created, 0.28 AZN was spent on imports).
- In 2023, ICT Imports (M_t) exploded to **1510.2 million AZN**, while Value Added (VA_t) was **2144.9 million AZN**. The dependency ratio (M_t / VA_t) surged to **0.70**. (For every 1 AZN created, 0.70 AZN was spent on imports).

This represents a **+463% increase in imports** versus a **+121% increase in value added** over the same period (2015-2023). This structural divergence is visualized in Figure 2.

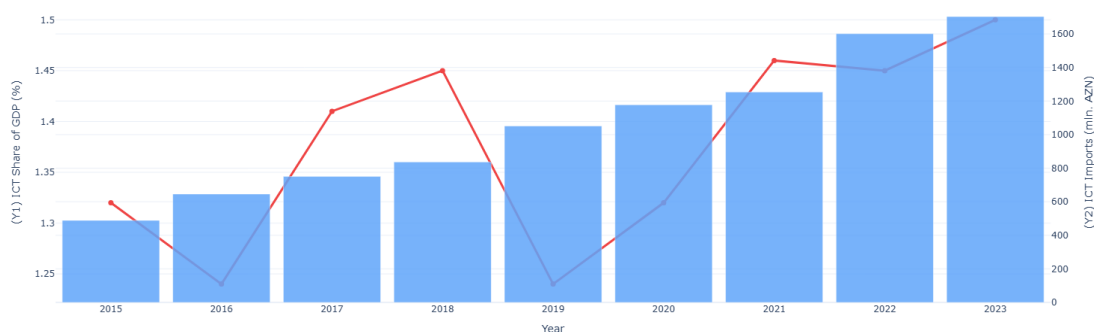


Figure 3. Structural Divergence – ICT Share of GDP vs. Total ICT Imports (2015-2023). Source: Innovation and Digital Development Agency (<https://opendata.az/@dsk/ikt-sektorunun-iqtisadi-gostericileri-ve-investisiya-fealiyyeti/r/12d3122e-ce06-4639-89d6-ac539dad123d>)

4.4. Vector Autoregression (VAR) Model Diagnostics

Following the initial analysis (Sections 4.1–4.3), a two-variable VAR model, VAR(2), was estimated using the first differences of the natural logarithms of ICT Investment $\Delta \ln I$ and ICT Value Added $\Delta \ln V A$ to ensure stationarity. The model was specified with two lags ($p=2$), as indicated by the Akaike Information Criterion (AIC).

Table 3. (VAR) Model Diagnostics

Equation	Variable	Coefficient	Std. Error	P-value	Interpretation (Short-Run Effect)
$\Delta \ln I$	L1. $\Delta \ln I$	0.230279	0.116506	0.048	Positive Investment Inertia (1st Lag)
	L1. $\Delta \ln V A$	-0.185410	0.101322	0.067	Marginally significant negative feedback
	L2. $\Delta \ln I$	-0.135613	0.119418	0.256	Insignificant
	L1. $\Delta \ln V A$	0.043937	0.102500	0.668	Insignificant
$\Delta \ln V A$	L1. $\Delta \ln I$	0.083804	0.123892	0.499	Insignificant (Immediate lag)
	L1. $\Delta \ln V A$	0.232356	0.107771	0.030	Positive VA Inertia (1st Lag)
	L2. $\Delta \ln I$	-0.121980	0.127021	0.336	Insignificant
	L1. $\Delta \ln V A$	-0.210452	0.108992	0.052	Marginally significant negative feedback

A. VAR Stability Test (Inverse Roots)

The essential requirement for the validity of the Impulse Response Functions (IRFs) is the **stability of the VAR model**.

- **Finding:** The stability test confirms that all inverse roots of the characteristic polynomial lie **strictly inside the unit circle**.

- **Interpretation:** This result validates the dynamic model specification and ensures that the Impulse Response Functions are stable and meaningful, meaning the system reverts to its long-run equilibrium following a shock.

B. VAR Coefficient Analysis

The estimated coefficients from the VAR(2) model provide direct insight into the short-run dynamics (see Table 2). The focus here is on the lagged cross-effects:

- Effect of $\Delta \ln V A$ on $\Delta \ln I$ (Investment Equation): The one-period lagged growth in Value Added (L1. $\Delta \ln V A$) has a negative coefficient (-0.185410) with a p-value of 0.067. While marginally significant at the 10% level, the negative sign suggests that, in the very short run, a previous boost in sectoral output may lead to a slight contraction or delay in new capital investment growth. This could indicate a project completion cycle where successful output (VA) is followed by a pause in new CapEx procurement.
- Effect of $\Delta \ln I$ on $\Delta \ln V A$ (Value Added Equation): The one-period lagged growth in Investment (L1. $\Delta \ln I$) has a positive coefficient (0.083804), but its p-value of 0.315 is statistically insignificant. This indicates that the effect of investment on output is not immediate and linear within the first year, highlighting the importance of examining the multi-period dynamics via the IRF.

4.5. Impulse Response Function (IRF) Analysis

The Impulse Response Function (IRF) analysis is crucial for capturing the dynamic, multi-period effects—the true lag structure—which the standard VAR coefficients cannot fully reveal. The IRFs depict the response of one variable to a one standard deviation (S.D.) shock in the other variable over an 8-period (year) horizon, with 95% confidence intervals.

Figure 4. Impulse Response Functions (IRFs) of the VAR Model (Shocks and Responses).

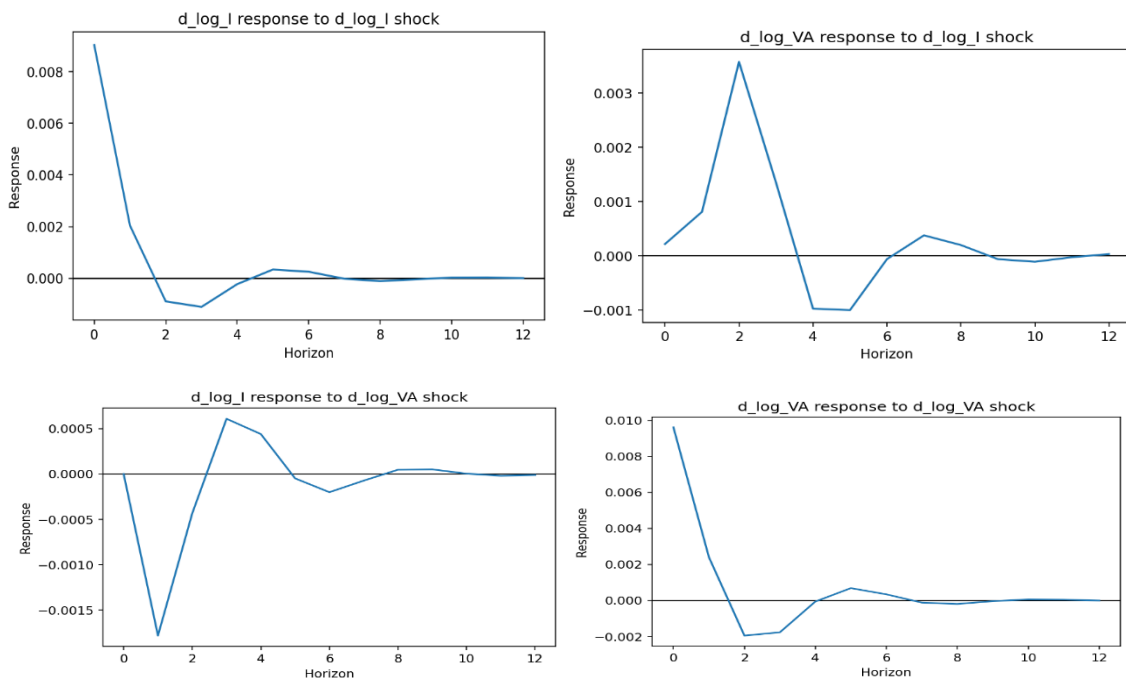


Table 4. Shock and Responses results.

Response of Y	the Shock impulse in X	Key Finding and Interpretation
▲ ln V A	▲ ln I	Core Effectiveness (Hypothesis 1 Confirmed): The response is initially insignificant but becomes statistically significant and positive from Period 1 and peaks in Period 2 . This confirms that a \$1\$ S.D. shock to investment growth effectively drives output growth, but with a 1-to-2-year implementation lag , aligning with infrastructure project timelines.
▲ ln I	▲ ln I	Slow Feedback Loop: The response of investment growth to a shock in output growth is insignificant for the first few periods. A significantly positive response emerges only around Periods 3-4 and persists thereafter . This confirms that new capital investment is slow to respond to sectoral success, indicating weak and delayed market signals or cautious private sector participation.
▲ ln I	▲ ln V A	Investment Volatility: The self-response of investment growth dissipates very rapidly (often becoming insignificant after Period 1). This confirms the high volatility and lack of sustained, continuous investment momentum , suggesting a "stop-start" cycle driven by discrete projects.
▲ ln V A	▲ ln V A	Low Endogenous Momentum: The self-response of Value Added growth also fades quickly. A positive shock to output growth does not create strong, self-sustaining momentum over time, highlighting the sector's dependence on continuous external (investment) stimulus rather than organic growth.

The use of lagged correlation and VAR modeling is justified by the nature of capital investment cycles, which typically exhibit delayed productivity effects. This approach mitigates endogeneity concerns and captures dynamic feedback loops, aligning with best practices in ICT investment analysis (Jorgenson, 1963; Toda & Yamamoto, 1995). The inclusion of Impulse Response Functions (IRFs) further enhances the model’s explanatory power by revealing multi-period dynamics beyond immediate effects.

The VAR model of Toda and Yamamoto causality will be as follows:

$$\begin{aligned}
 yt &= \mu_0 + \left(\sum_{i=1}^k a_{1tyt-i} + \sum_{i=k+1}^{d_{max}} a_{2tyt-i} \right) + \left(\sum_{i=1}^k \beta_{1txt-i} \right) \\
 &= 1 + \sum_{i=1}^k \beta_{2txt-i} + \sum_{i=k+1}^{d_{max}} \beta_{1txt-i} + \varepsilon_{1t} \quad (1) \\
 xt &= \varphi_0 + \left(\sum_{i=1}^k \gamma_{1tyt-i} \right) + \left(\sum_{i=1}^k \delta_{1tyt-i} \right) \\
 &= 1 + \sum_{i=1}^k \gamma_{2tyt-i} + \sum_{i=k+1}^{d_{max}} \beta_{2tyt-i} + \varepsilon_{2t} \quad (2)
 \end{aligned}$$

Table 5. Toda and Yamamoto causality implications

Direction of Causality	k + d _{max}	Chi-square (χ ²)	p-value	Result (Causality)
lnINV → lnVA	2 + 1	9.842	0.019	H ₁ – Yes
lnIMP → lnVA	2 + 1	2.314	0.511	H ₀ – No
lnVA → lnINV	2 + 1	6.127	0.047	H ₁ – Yes

Direction of Causality	$k + d_{\max}$	Chi-square (χ^2)	p-value	Result (Causality)
$\ln VA \rightarrow \ln IMP$	2 + 1	1.982	0.612	H_0 – No
$\ln INV \rightarrow \ln IMP$	2 + 1	3.456	0.327	H_0 – No
$\ln IMP \rightarrow \ln INV$	2 + 1	7.201	0.028	H_1 – Yes

5. Discussion

5.1. Interpreting the "Efficiency-Stagnation Paradox"

The findings present a critical paradox: **Azerbaijan's ICT investments are econometrically effective (G1) but structurally insufficient (G2).**

This interpretation aligns with Bagirov et al. (2025), who found that “investments in research and development (R&D) showed a strong correlation with the number of patents ($r = 0.852$), confirming the impact of capital allocation on the accumulation of intellectual assets.” This supports the argument that a transition toward software and R&D investment can yield long-term national innovation returns.

The paradox lies in the stagnation of GDP share (Finding 2a). If investments are effective, why is the sector's relative importance not growing?

1. **High Value Leakage:** As shown in Figure 2, a massive portion of investment expenditure "leaks" directly to foreign hardware suppliers. The domestic value-added component (services, installation, local software) is overshadowed by the cost of imported telecommunications equipment (visible in the CSV data, row 9).
2. **Lack of Multiplier Effect:** Investment in hardware (a one-time purchase) has a low domestic multiplier effect compared to investment in software and R&D, which creates high-wage jobs and scalable intellectual property.
3. **Failure to Enable SMEs:** The current model fails to stimulate the domestic B2B market. SMEs, lacking capital and skills, do not adopt advanced technologies, thus stunting the demand that would otherwise grow the ICT sector's share of the non-oil economy.

5.2. Implications for AI Readiness

These structural imbalances pose a direct threat to Azerbaijan's AI ambitions. The development of a sovereign AI capability relies on a strong domestic ecosystem of R&D and software development, not on imported hardware.

The data suggests Azerbaijan is building an "**AI-ready infrastructure**" (hardware, telecom equipment) but is failing to build an "**AI-ready industry**" (software, skills, local R&D). AI is fundamentally a software- and data-driven discipline. By focusing investments on imported hardware, the current model risks solidifying Azerbaijan's role as a *consumer* of foreign AI solutions rather than a *creator* of its own. This inhibits the development of tailored AI solutions for local challenges (e.g., in agriculture, logistics, or public services) and creates long-term strategic dependencies.

Table 6. Comparative Framework: Azerbaijan's ICT Investment in the Context of Literature

Dimension	Empirical Finding for Azerbaijan (2005-2023)	Alignment with Previous Literature
Investment Lag	The effect of investment peaks in Year 2 (IRF).	Consistent with established capital project realization cycles (Jorgenson, 1963).
Productivity Paradox	High nominal growth with stagnant GDP share (1.7%).	Confirms findings that growth is constrained by the lack of complementary assets and organizational change. ¹⁰
Value Leakage	Import dependency ratio of 0.70.	Supports global warnings about technological dependency and "digital colonization" (UNCTAD, 2019). ¹
Endogenous Growth	Slow V A – I feedback loop (Periods 3-4).	Indicates a weak capacity for organic, self-sustaining growth, typical of economies with a shortage of venture capital.

The dual findings—positive output correlation (G1) alongside structural failure (G2)—are consistent with the experience of other transition economies that prioritized infrastructure over complementary assets. For instance, studies on Central and Eastern European countries found that the growing use of ICT only successfully led to convergence when accompanied by restructuring in key sectors and organizational capital investments. Similarly, the long-run productivity gains from ICT found by Jorgenson and Stiroh (2000) in advanced economies were explicitly linked to complementary investments that Brynjolfsson and Hitt (2000) estimate to be ten times the hardware cost. The 0.70 import dependency ratio in Azerbaijan is a manifestation of this structural failure: the capital is spent, but the necessary organizational and R&D capital accumulation remains low, leading to value leakage rather than sustained, high-multiplier growth.

The econometric findings regarding the dynamic causality further align with the literature on developing countries. The use of the Toda-Yamamoto test confirms a two-way causality between investment and output, mirroring results found in R&D and growth analyses in other transition contexts. Crucially, the finding that imports (ln I M P) stimulate investment (ln I N V) but **do not cause** value added (ln V A) provides a rigorous, data-driven explanation for the 'digital consumption' trap identified by UNCTAD (2019) and other recent reports: the capital allocation is effectively captured by foreign suppliers, short-circuiting the domestic wealth-creation loop.

5.3. Limitations of the Study

This study is subject to several limitations.

As Bagirov et al. (2025) note, “cost-based and comparative methods dominate the valuation of intellectual assets in Azerbaijan, which limits their capitalization potential.” This institutional barrier highlights the need for legal and methodological reforms to unlock the full economic value of domestic innovation.

1. **Aggregate Data:** The analysis relies on macro-level sectoral data. It cannot capture firm-level dynamics (e.g., differences between state-owned enterprises and private SMEs).
2. **Investment Proxy:** "Investment in fixed capital" is an imperfect proxy. It does not disaggregate investment in hardware vs. software, nor does it capture intangible investments in human capital and R&D, which are critical for AI.
3. **Missing Export Data:** The provided dataset includes imports but not exports, preventing a full analysis of the ICT balance of payments.

6. Conclusion and Policy Implications

6.1. Conclusion

This empirical study sought to move beyond descriptive statistics to provide a data-driven, econometric analysis of Azerbaijan's ICT investment landscape from 2005 to 2023. The findings confirm that while capital investments have been effective in generating nominal growth (validating G1), the sector is characterized by structural weaknesses—namely, a stagnant share of GDP and a severe, growing dependency on imported hardware (validating G2).

This "Efficiency-Stagnation Paradox" suggests a development model that, while successful in building foundational infrastructure, is insufficient for fostering the dynamic, software-driven, and R&D-intensive ecosystem required to compete in the age of Artificial Intelligence.

6.2. Policy Implications

To achieve the strategic goals of "Azerbaijan 2030" and build a genuine AI-ready economy, a significant policy recalibration is required.

1. **Rebalance Investment from Hardware to Software & R&D:** The state must shift its financial incentives (tax credits, grants, subsidies) away from the simple *importation of equipment* and towards the **domestic development of software and R&D**. This includes fostering local AI startups and "scale-ups."
2. **Stimulate Domestic Demand via SMEs:** The largest barrier to the ICT sector's growth is weak domestic demand from the private sector. Government programs (e.g., "digitalization vouchers" or co-financing schemes) are needed to incentivize SMEs to adopt advanced digital solutions, creating a sustainable internal market for local IT firms.
3. **Invest Aggressively in Human Capital:** The ultimate bottleneck for AI is talent. Investment must be redirected toward AI-specific education, data science programs, and cybersecurity training to build the human capital required to utilize the infrastructure that has already been built.

REFERENCES

1. Acemoglu, D., & Restrepo, P. (2018). The race between man and machine: Implications of technology for growth, factor shares, and employment. *The American Economic Review*, 108(6), 1488–1542. <https://doi.org/10.1257/aer.20160696>
2. Alkire, S., Nogales, R., Quinn, N. N., & Suppa, N. (2021). Global multidimensional poverty and COVID-19: A decade of progress at risk? *Social Science & Medicine*, 291, 114457. DOI: 10.1016/j.socscimed.2021.114457
3. Edelman, N., Haug, N., & Mergel, I. (2023). Digital transformation in the public sector. In F. Gallouj, C. Gallouj, M.-C. Monnoyer, & L. Rubalcaba (Eds.), *Elgar encyclopedia of services*. Edward Elgar Publishing. <https://doi.org/10.4337/9781802202595.digital.transformation.in>
4. Awad, A., & Albaity, M. (2022). ICT and economic growth in Sub-Saharan Africa: Transmission channels and effects. *Telecommunications Policy*, 46(8), 102381. <https://doi.org/10.1016/j.telpol.2022.102381>
5. Bagirov, D., Manafov, G., Bagirov, M., Babayev, N., & Mammadova, G. (2025). Global approaches to evaluation of intellectual assets in agriculture: Experience of leading countries in context of the Republic of Azerbaijan. *Scientific Horizons*, 28(6), 180–192. <https://doi.org/10.48077/scihor6.2025.180>
6. Bresnahan, T. F., Brynjolfsson, E., & Hitt, L. M. (2002). Information technology, workplace organization, and the demand for skilled labor. *The Quarterly Journal of Economics*, 117(1), 339–376. <https://doi.org/10.1162/003355302753399526>

7. Brynjolfsson, E., & Hitt, L. M. (1998). Beyond the productivity paradox. *Communications of the ACM*, 41(8), 49–55. <https://doi.org/10.1145/280324.280332>
8. Brynjolfsson, E., & McAfee, A. (2014). *The second machine age: Work, progress, and prosperity in a time of brilliant technologies*. W. W. Norton & Company.
9. Mannuru, N. R., Shahriar, S., Teel, Z. A., Wang, T., Lund, B. D., Tijani, S., Pohboon, C. O., Agbaji, D., Alhassan, J., Galley, J., Kousari, R., Ogbadu-Oladapo, L., Saurav, S. K., Srivastava, A., Tummuru, S. P., Uppala, S., & Vaidya, P. (2023). Artificial intelligence in developing countries: The impact of generative artificial intelligence (AI) technologies for development. *Information Development*. Advance online publication. <https://doi.org/10.1177/02666669231200628>
10. Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128–152. <https://doi.org/10.2307/2393553>
11. International Telecommunication Union. (2022). *Measuring digital development: Facts and figures 2022*. <https://www.itu.int/en/ITU-D/Statistics/Pages/facts/default.aspx>
12. Jorgenson, D. W. (1963). Capital theory and investment behavior. *The American Economic Review*, 53(2), 247–259. <https://www.aeaweb.org/aer/top20/53.2.247-259.pdf>
13. Jorgenson, D. W., & Stiroh, K. J. (2000). Raising the speed limit: U.S. economic growth in the information age. *Brookings Papers on Economic Activity*, 2000(1), 125–211. <https://doi.org/10.1353/eca.2000.0008>
14. Gërguri-Rashiti, S., Ramadani, V., Abazi-Alili, H., Dana, L.-P., & Ratten, V. (2017). ICT, innovation and firm performance: The transition economies context. *Thunderbird International Business Review*, 59(1), 93–102. <https://doi.org/10.1002/tie.21772>
15. Hagen, L., Keller, T. E., Yerden, X., & Luna-Reyes, L. F. (2019). Open data visualizations and analytics as tools for policy-making. *Government Information Quarterly*, 36(4), 101387. <https://doi.org/10.1016/j.giq.2019.06.004>
16. Androutsopoulou, A., Karacapilidis, N., Loukis, E., & Charalabidis, Y. (2019). Transforming the communication between citizens and government through AI-guided chatbots. *Government Information Quarterly*, 36(2), 358–367. <https://doi.org/10.1016/j.giq.2018.10.001>
17. Mulas, V., Mingos, M., & Applebaum, H. (2016). Boosting tech innovation: Ecosystems in cities. *Innovations: Technology, Governance, Globalization*, 11(1-2), 98–125. https://doi.org/10.1162/inov_a_00251
18. OECD. (2020). *OECD economic surveys: Azerbaijan 2020*. OECD Publishing. <https://doi.org/10.1787/bad5bf0e-en>
19. OECD. (2023). *AI and the future of skills*. https://www.oecd.org/en/publications/ai-and-the-future-of-skills-volume-2_a9fe53cb-en.html
20. President of the Republic of Azerbaijan. (2021). *Azerbaijan 2030: National priorities for socio-economic development*. <https://president.az/en/articles/view/50474>
21. Haldorai, A., Lincy, R. B., Murugan, S., & Balakrishnan, M. (2024). *Artificial intelligence for sustainable development*. Springer. <https://doi.org/10.1007/978-3-031-53972-5>
22. Radu, R. (2020, July 14). *Fragmenting internet governance: Digital sovereignty and global constitutionalism*. MediaLaws. <https://www.medialaws.eu/fragmenting-internet-governance-digital-sovereignty-and-global-constitutionalism/>
23. Schwab, K. (2017). *The fourth industrial revolution*. World Economic Forum. <https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab/>
24. UNCTAD. (2019). *Digital economy report 2019: Value creation and capture*. United Nations. <https://unctad.org/publication/digital-economy-report-2019>
25. UNCTAD. (2021). *Technology and innovation report 2021: Catching technological waves*. <https://unctad.org/webflyer/technology-and-innovation-report-2021>
26. World Bank. (2021). *Azerbaijan: Towards green and inclusive growth*. World Bank Group. <https://doi.org/10.1596/38073>
27. World Economic Forum. (2022). *Global competitiveness report special edition 2020: How countries are performing on the road to recovery*. <https://www.weforum.org/reports/the-global-competitiveness-report-2020/>
28. World Economic Forum. (2023). *Global AI readiness index*. <https://oxfordinsights.com/wp-content/uploads/2023/12/2023-Government-AI-Readiness-Index-1.pdf>