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Assessing the Impact of ICT on Economic Growth in Tunisia: A Cointegration Approach

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ABSTRACT
This study aims to investigate how Information and Communication Technology (ICT) will affect economic growth in Tunisia country for the period 1990 – 2023 using cointegration approaches and error correction model (ECM). The study is based on the neoclassical growth model and the use of a famous Cobb-Douglas production function as in the main studies in this field. To this end, capital is distinguished between ICT and non-ICT capital to determine their impact on economic growth. The most recent developments in this domain include particularly the works of **Aralica, Z., & Škrinjarić, B. (2021)**. and **Hwang, W.-S., & Shim, D. (2021).**which hold the position that ICT is an essential enabler of productivity and innovation, especially in the developing economies. This research work results shows that there is a long-run relationship between the economic growth and the development of ICT, specifically in the telecommunications sector. These findings are important in validating the role of ICT as an important engine of economic growth. They agree with the global patterns and imply that directed investment into ICT combined with suitable regulatory environment can boost economic growth in the long run. The current study enriches the existing body of knowledge on ICT and economic growth and is, therefore, useful to policymakers in Tunisia and other similar economies.

Keywords: Economic Growth, ICT, Neoclassical model, Cobb Douglas, Cointegration, ErrorCorrectionModel

I. INTRODUCTION

The impact of Information and Communication Technology (ICT) on productivity and economic growth is well recognized in economic literature and substantiated by strong theoretical models and empirical evidence across countries. Yet this link has been primarily studied in advanced economies, whereas it is under-explored in emerging markets, especially for North African countries like Tunisia. Tunisia's experience deserves a thorough quantitative assessment of the extent to which strategic modernization initiatives and regulatory reforms integrated into the development agenda of Tunisia through ICT, transform into monetizable growth outcomes despite efforts at implementing the measures. This has left a crucial knowledge gap that the current work attempts to fill by using annual data from 1990 up to 2023 to analyze the short- and long-run impacts of ICT adoption on Tunisia through a cointegration techniques and an error correction modelling. The research is grounded within neoclassical growth theory through which ICT's distinct contribution is identified and Tunisia's digital transformation is contextualized within broader debates about technology-led development in resource constrained setting. The findings aim to provide actionable insights for policymakers seeking to optimize ICT's potential as a catalyst for sustainable growth while contributing empirical depth to the discourse on digital economies in the Global South.

Our approach consists of four stages; Initially we thoroughly examine research, on the relationship between ICT and economic advancement by combining patterns and theoretical underpinnings. Next, we investigate the aspects and evolution of Tunisia telecommunications industry

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as a component of ICT. Then we utilize methods such as cointegration analysis and error correction models to measure both the immediate and lasting impacts of ICT, on Tunisia s overall economic environment. We carefully assess the limitations of the study. Suggest ways to enhance the benefits of ICT, for development purposes. In our research work we deepen our understanding of how ICTs drive growth in developing economies by combining analysis with real world validation data. We also offer strategies tailored to stakeholders in Tunisia and other similar countries who are ready to change. Our goal is to tie discussions to policy frameworks for technology-enabled development strategies by integrating sector analysis, time-based modeling and policy recommendations.

II. EVOLUTION OF ICT-GROWTH RESEARCH: FROM PARADOX TO RECOGNITION

The impact of Information and Communication Technology (ICT) on economic performance has been a rigorous debate since the last century with methodological innovations and changing analytical paradigms.This empirical work was mainly conducted in developed economies such as the United States and seeks at quantifying the macroeconomic impacts of ICT but were often not conclusive or even controversial. This ambivalence resulted in the so-called 'productivity paradox' or 'technological paradox', which was sparked by Solow's caustic comment that computers were 'everywhere but in productivity statistics' that raised doubts about the productivity benefits of ICT. Following on from the work of **Oliner and Sichel (1994)** and **Jorgenson and Stiroh (2000)**, it has been proposed that organizational inefficiencies and incomplete measurement frameworks have led to an underestimation of the impact of ICT, while conventional growth models have failed to take account of complementary investments in software, training and process re-engineering.

The Productivity Paradox: Measurement Challenges:

On the basis of US data from 1970 to 1992, **Oliner and Sichel (1994)**concluded that information and technologies capital has a relatively small contribution to GDP growth (16%-39%) due to the relative importance of the latter in aggregate capital stock. The problem, they argued, is that existing studies have relied on too narrow a definition of ICT, one that is based solely on expenditures on hardware. They further suggested that if software costs and IT-related labor costs were also incorporated into the analysis then the share of IT in the contribution might be as much twice as much as it is currently estimated. However, this also meant that existing levels of growth were being hindered by persistent underinvestment in information systems throughout this era.

OECD Insights: Broadening the ICT Narrative:

Karsenti (1997) extended the scope of ICT to include hardware, software and human capital in his cross-national study of 25 OECD economies between 1987 and 1995. His findings refuted the productivity paradox by showing real growth contributions of ICT. The Market Creation theory: New forms of network technologies created new markets.

The Growth Elasticity: The elasticity of output to ICT capital was about 0.2, and ICT added 0.6 percent to 0.8 percent to GDP growth.

Higher Returns: Marginal product of ICT capital was higher than that of traditional capital. However**, Karsenti** was very much aware that the effects were not uniformly sectoral and that ICT was a modernizing way, but complementary rather than substitutive.

Sectoral Asymmetries and Substitution Effects:

In his 1999 book, Gordon showed deep flaws in the productivity acceleration hypothesis, as the gains from ICT investment were skewed towards the ICT supplying industries, while other industries, such as durable goods manufacturing, showed either no growth or decline. This was supported by **Jorgenson and Stiroh** who argued that the limited sectoral dissemination of ICT was due to price induced substitution towards non-ICT capital goods, without the accompanying productivity benefits. These results suggested the importance of sector focused studies and the necessity of complementary structural adjustments.

Emerging Economies and Digital Transformation

Research by **Czernich et al. (2021)** and **Vu et al. (2020)** however changes the perspective to the holistic impact of ICT on developing nations. It is revealed that the rate of broadband penetration and digital adoption accelerates GDP growth and innovation depending on how easily the diffusion is supported by regulatory frameworks (**Arellano et al., 2022**). These studies stress the multiplier

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effects of ICT in resource constrained environments where infrastructure gaps and institutional barriers have in the past restricted technological spillovers.

Tunisian Context: Bridging the Research Gap

While research on global literature is extensive, that focusing on Tunisia is still in its infancy but growing. **Ben Hassen (2017)** points out that growth drivers are digital infrastructure and regulatory modernization, while **Ghazouani (2020)** stresses the positive impact of ICT on labor productivity, particularly in the service sector. **Bouhlel et al. (2021)** recommend targeted policies to enhance the developmental impact of ICT. Accordingly, these works are quoted as acknowledging Tunisia's advancement in the integration of ICT but calling for more detailed empirical analysis of the growth mechanisms and distributional impacts.

Positioning This Study

Although North Africa and Tunisia in particular are little explored in the ICT-growth discourse, which is richly evidenced globally, this paper fills this gap by examining Tunisia's 1990–2023 trajectory using cointegration and error correction models extending prior frameworks to a dynamic emerging economy. The research dissects both temporal and sectoral impacts of ICT and by linking theoretical insights to Tunisia's distinctive developmental context the paper provides actionable guidance for course steering through digital transition by policymakers.

Synthesis of Key Empirical Findings

The table below summarizes pivotal studies on ICT's GDP growth contributions, illustrating methodological evolution and contextual variability:

Table1:**Synthesis of key Empirical Findings**

Study	Period	Key Findings
Oliner and Sichel (1994)	1970–1992	IT capital contributed 0.16%–0.39% to GDP growth; inclusion of computing services doubled this contribution.
Karsenti (1997)	1987–1995	ICT contributed 0.6%–0.8% to GDP growth; Solow paradox no longer applicable.
Gordon (1999)	1995–1999	Productivity gains limited to ICT-producing sectors; other sectors stagnated.
Jorgenson and Stiroh (2000)	1990s	ICT substitution effect observed, but limited impact on total factor productivity outside ICT sector.
Czernich et al. (2011)	1996-2007	Broadband penetration significantly enhances

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		GDP growth, especially in developing countries.
Vu et al. (2020)	1991-2018	ICT diffusion fosters innovation and productivity in emerging markets.

This synthesis underscores ICT's evolving role—from contested contributor to recognized growth lever—while highlighting persistent gaps in emerging economy research.

III. TUNISIA'S TELECOMMUNICATIONS SECTOR PERFORMANCE

In the twenty years or so Tunisia has been focusing on using Information and Communication Technologies (ICT) to boost its economy. Through the implementation of plans such as the National Digital Strategy 2025 and the Digital Tunisia 2020 Plan the country has been developing its infrastructure, expanding broadband services and promoting literacy.

These actions have enabled Tunisia to come up as a player in the ICT sector in the region moving from position in the UN ICT Development Index in 2012 to 91st globally in 2020 and leading Africa in network readiness.

Key ICT Infrastructure Trends (2010–2023)

The table below highlights Tunisia's progress across critical ICT metrics, underscoring both achievements and persistent challenges:

Table2:**Tunisia's progress across critical ICT metrics**

Indicator	2010	2023	Growth
Fixed & mobile subscribers (thousands)	12,404	18,222.4	+46.9%
Tele density (per 100 inhabitants)	117.0	153.1	+30.8%
Computers per 100 inhabitants	13.1	38	+190%
Household computer penetration	19.1%	67%	+250%
Internet subscribers (per 100)	15.0 (2011)	112.0	+646%
Household internet penetration	11.4%	65.2%	+472%
Total websites	11,873	57,920	+388%
Broadband capacity (Gb/s)	37.5	1,880	+4,913 %

Sectoral Analysis & Global Benchmarks - Connectivity Expansion:

Tunisia has made significant strides in telecom accessibility as mobile and fixed-line subscriptions nearly doubled, reaching 18.2 million in 2023, an increase of 46.9% from 12.4 million in 2010. Post-2011 revolution reforms catalyzed this growth, with the government placing high demands on modernization of its digital infrastructure to improve the growing need for connectivity. Despite those advances, Tunisia lags global leaders like South Korea — where more than 60 million subscribers enjoy near-universal mobile take-up. To reduce this lag, we need to make strategic investments in 5G. To narrow this gap, strategic investments in 5G network expansion and competitively priced mobile packages are essential

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to enhance affordability and inclusivity in Tunisia's digital ecosystem.

- **Tele density Gains:**

Tunisia's tele density—or number of telephone connections for every 100 inhabitants—increased from 117.0 in 2010 to 153.1 in 2023, suggesting that growth in telecom services had overtaken demographic growth. This trajectory was sustained by post-2011 revolution reforms that made connectivity central to economic development and social equity. Despite the improvements, Tunisia is still behind other countries, e.g. Singapore (tele density: 180) where the development of a large infrastructure and affordable access models have led to nearly universal coverage. To bridge the digital divide, policymakers must address the strategic infrastructure initiatives in the underserved rural regions, along with the subsidized pricing programs for low income families where no one should be left behind in the digital inclusion journey.

- **Device Accessibility:**

Over the period 2010-2023, the uptake of computers increased by 190% in Tunisia, and the number of devices per one hundred inhabitants increased from 13.1 to 38. This growth was driven by both digital transformation agendas and education modernization, after the 2011 revolution initiated widespread reforms which led to this growth. However, this is a success story, and Tunisia is behind countries like the USA, which has more than 90+ computers for every 100 residents. To address these technology disparities, implementing national student subsidy programs for device acquisition, alongside national, cost-effective, community-driven digital literacy programs could democratize access and encourage technology inclusivity.

- **Digital Household Adoption:**

In Tunisian household's computer adoption increased from 19.1% in 2010 to an astonishing 67% by 2023 (250% increase). For the most part, this expansion occurs after the pro-revolutionary reforms with the emphasis on digital inclusion and the universality of digital divide by families who need computers for education or occupation. Yet Tunisia lags behind countries like Norway, where computer ownership is more than 95% of households. Beyond mere access to public computer points and the incentives for financial household technology adoption, these should be the solutions that policymakers should be offering to fill this gap.

- **Internet Accessibility:**

Between 2011 and 2023, there was an amazing 646% increase in internet adoption rates due to subscribers per 100 inhabitants going from a low of 15.0 to a high of 112.0 in Tunisia This surge was in part made possible by post-2011 reforms which focused on expanding digital infrastructure, solidifying the internet's dual status as a tool for both civic engagement and economic mobilization. While having this a step forward Tunisia still lags behind global best-in-businesses such as Iceland with 99% internet access complemented by superior network performance in terms of metrics. Strategic investments in fiber – as well as broad-based rural broadband expansion will be needed if we are to close this gap and ensure inclusive digital inclusion and sustain economic modernization.

- **Online Ecosystem Growth:**

Between 2010 and 2023, Tunisia's digital ecosystem grew very rapidly with the number of active websites increasing 388% from 11,873 to 57,920. This expansion was due to post-2011 reforms that opened up the digital space and created an environment for online platforms to grow. Despite this progress, Tunisia's digital footprint remains modest compared to global leaders like the United States, which hosts millions of domains. To accelerate growth, targeted measures such as **startup incubators for tech ventures**, **grants for SME digitization**, and **local content creation incentives** could amplify Tunisia's presence in the global digital economy.

- **Broadband Leap:**

Tunisia's broadband infrastructure witnessed an extraordinary expansion, soaring from 37.5 Gb/s in 2010 to 1,880 Gb/s by 2023—a staggering 4,913% increase. This transformation was fueled by post-2011 reforms that prioritized governance transparency and economic revitalization, driving strategic investments in high-speed internet to align with global technological advancements. Despite this progress, Tunisia trails pioneers like South Korea, which boasts broadband capacities exceeding 2,500 Gb/s. To narrow this gap, accelerating the rollout of fiber-optic networks and prioritizing 5G infrastructure development are essential to fortify Tunisia's position in the global digital economy.

Since the 2011 revolution, Tunisia has made significant steps in the development of the

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telecommunication and digital infrastructure through the modernization of policies and strategies, and the implementation of digital reforms. There has been enhancement of the broadband rollout, e-governance, and tech literacy campaigns as drivers of the connectivity metrics. Nevertheless, there are still existing disparities in some important fields: The network reliability is not as high as the global standards (for instance South Korea with 5G ubiquity), the average internet speeds are lower than the OECD standards, device accessibility (38 computers per 100 inhabitants) is below the levels of advanced economies, and the digital content creation is still in the novice level when compared with Silicon Valley. To enhance global competitiveness, Tunisia should adopt the following best practices of the frontrunner nations:

1. Infrastructure Overhaul: Focusing on the improvement of the network quality through enhancement of fiber optic infrastructure and implementation of 5G networks.
2. Affordability Initiatives: Provide subsidized access to devices for people in need and encourage the development of tech products in the local market.
3. Content Ecosystem Development: Assist digital innovation hubs and streamline regulations for startups to grow.
4. Public-Private Synergies: Team up with global tech firms to co-invest in R&D and skills development.

If the policy framework is to be aligned to these pillars of the competitive strategy, Tunisia can build on its digital momentum to achieve sustainable and inclusive growth and become a tech hub in North Africa. The development of telecommunications has been an essential factor in economic development and the creation of new opportunities for cross-sectoral development, including education, telemedicine, and digital commerce. Although these developments have enhanced connectivity-driven growth, to realize the full developmental potential of ICT, the existing divide in infrastructure modernization, cost, and access to digital tools must be addressed. The expansion of rural broadband coverage through the subsidization of affordable devices and the implementation of inclusive digital literacy programs remains a necessity to ensure that all citizens and enterprises in the nation can access and benefit from the digital transformation.

IV. ECONOMETRIC MODEL

To assess the effect of Information and Communication Technology (ICT) on economic development, this study uses a neoclassical growth model based on a Cobb-Douglas production function. This model examines the role of three main inputs of capital, labor and total factor productivity (TFP) in driving macroeconomic output. Based on the previous work of **Bryjolfsson and Hitt (1996)**, **Jorgenson (2001)** and **Gilles and Horty (2003)**, we break down capital stock into two categories of capital: ICT capital (KICT) and non-ICT capital (Knon−ICT). This allows to exclude the ambiguity between the effects of technological and traditional capital. Hence, using the logarithmic transformation of the Cobb-Douglas function, we obtain the linear specification for the econometric model:

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Model Specification

$$LogY_t = LogA_t + \alpha_1 LogK_{ICT_t} + \alpha_2 LogK_{NICT_t} + \alpha_3 LogL_t + \varepsilon_t$$

Variable Definitions

- $\mathbf{Y_t}$**:** Real GDP, serving as the proxy for aggregate output.
- $\mathbf{A_t}$: Total Factor Productivity (TFP), encapsulating technological innovation, institutional efficiency, and unobserved growth drivers.
- $\mathbf{KICT_t}$: ICT capital stock, including digital infrastructure (broadband, telecom networks), hardware, and software investments.
- $\mathbf{Knon{-}ICT_t}$: Non-ICT physical capital (machinery, buildings, transport systems).
- $\mathbf{L_t}$: Labor input, measured via workforce participation or hours worked.
- 1, 2, 3: Output elasticities quantifying the marginal productivity of ICT capital, non-ICT capital, and labor, respectively.
- ϵ_t: Stochastic error term accounting for measurement inaccuracies and exogenous shocks.

This analytical framework offers a systematic approach to quantify the specific role of ICT capital, non-ICT capital, and labor inputs in the economic growth process while also capturing the role of Total Factor Productivity (TFP) as a separate contributor to output growth. We quantify how much effect ICT investments have on GDP output elasticities denoted as 1, 2**and** 3.
To ensure methodological rigor, robustness checks by means of advanced econometric validation are carried out:

- Tests for Stationarity: The ADF and PP tests are used to analyze non-stationarity in time series data.
- Cointegration Analysis: Johansen's procedure determines the existence of the long-run equilibrium relationship between variables.
- Diagnostic Tests: The Breusch-Pagan and Durbin-Watson tests are used to detect heteroskedasticity and autocorrelation, respectively, to ensure that OLS assumptions are satisfied.

This methodology ranges from theoretical to empirical, thus providing a reusable model for analyzing digital transformation in emerging markets.

V. DATA FRAMEWORK

This study investigates the influence of Information and Communication Technology (ICT) on Tunisia's economic growth by analyzing annual time-series data (1990-2023) across key macroeconomic indicators. The table below details the operational definitions, measurement methodologies, and data sources for the variables employed in the empirical framework.

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Table3:**Variable Definitions and Sources**

Variable	Measure	Source
Y(output)	GrossDomesticProduct(GDP)	NationalInstituteofStatistics(themainaccounts)
K(totalcapitalstock)	annualseriesofGrossFixedCapital Formation(GFCF)	NationalInstituteofStatistics(the nationalaccounts)
L(Labor)	LaborSeriesinnumbers	National Institute of Statistics(Surveys and Census of the Tunisian population)
K_{ICT}(Capitalstockofinformationandcommunicationtechnology sector)	Annual series of Gross Fixed CapitalFormationofthecommunications sector	Ministry of Information andCommunication Technology, PromotionAgencyIndustry
K_{NICT}(CapitalStockofoutside informationand communicationtechnology sector)	Thedifferencebetweentotalcapitalstock and capital stock of information and communicationtechnology	**Calculated as $K_{NICT=}$ K- K_{ICT}**

VI. THE ESTIMATION RESULTS

6.1 Unit Root Testing: Augmented Dickey-Fuller (ADF) Methodology

Conventional econometric models assume stationarity—statistical properties (mean, variance) remaining constant over time. However, macroeconomic time series often exhibit non-stationarity (unit roots), violating this assumption and risking spurious regression outcomes. Non-stationarity invalidates standard statistical inference, necessitating specialized techniques to ensure robust parameter estimates.

We employ **the Augmented Dickey-Fuller (ADF) test**, a widely accepted parametric procedure for detecting unit roots. The ADF framework extends the Dickey-Fuller test by incorporating lagged differences to mitigate autocorrelation, following the regression:

$\Delta yt=\alpha+\beta t+\gamma yt-1+\sum i=1p\delta i\Delta yt-i+\epsilon t\Delta yt =\alpha+\beta t+\gamma yt-1+i=1\sum p\ \delta i\ \Delta yt-i\ +\epsilon t$

where Δyt is the differenced series, α is a constant, βt captures a deterministic trend, and γ tests the null hypothesis of a unit root ($\gamma=0$).

Implementation Strategy

1. **Sequential Testing**: A three-stage approach is adopted:
   - Test for unit roots in **level form** (with trend and intercept).
   - If non-stationary, test **first differences**.
   - Determine optimal lag length via criteria (AIC/SBC) to eliminate autocorrelation.
2. **Interpretation**: Rejection of the null hypothesis ($\gamma<0\gamma<0$) confirms stationarity.

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Table4: **UnitRootTest (Augmented Dickey-Fuller (ADF) Tests)**

Variable	Test Type	ADF Statistic	p-value	Conclusion
LN GDP	Level (Trend)	-0.658	0.844	Non-stationary
	First Difference	-5.987	0.000***	Stationary (I(1))
LN L	Level (Trend)	-1.049	0.7236	Non-stationary
	First Difference	-8.889	0.000***	Stationary (I(1))
LN TIC	Level (Trend)	-1.75	0.72	Non-stationary
	First Difference	-4.75	0.002***	Stationary (I(1))
LN NTIC	Level (Trend)	-1.95	0.60	Non-stationary
	First Difference	-5.03	0.000***	Stationary (I(1))

The Unit Root Test results show that all the variables: LNGDP (log GDP), LNKICT (log of ICT capital), LNKNICT (log of non-ICT capital) and LNL (log of labor) are non-stationary in level but stationary at first difference. This places them in the **I (1)** category, which means that there are permanent components in Tunisia's economic and ICT development over the sample period.

The non-stationary nature of these variables is a clear picture of Tunisia's economic structure during the sample period, which has been characterized by the implementation of structural reforms and institutional changes that began after the 2011 revolution. The political upheaval was a catalyst for policy making, including the rapid advancement in the ICT sector through initiatives like the Digital Tunisia 2020 Plan and the National Digital Strategy 2025. This commitment is evident by the fact that there was 50 times increase in the broadband capacity (was 37.5 Gb/s in 2010 to 1,880 Gb/s in 2023) which has facilitated the development of e-governance, fintech, and digital delivery of public services. At the same time, the restructuring of the labor market through vocational training and partnership between the public and private sectors was meant to align the labor market with the needs of the ICT sector.

These insights become even more crucial as Tunisia deepens its integration into tech supply chains, which requires cointegration models to capture stable long-term economic relationships. These findings highlight the continued need for policy makers to sustain investment in the ICT sector, while also closing systemic gaps: rural internet access, scaling up of digital literacy programs and broadening equity in labor market policies to make sure that growth is sustainable and inclusive.

6.2 Johanson Cointegration Test

Since all the variables used in this analysis are **I (1)**, we apply the Johansen cointegration test to check for the existence of a long-run equilibrium relationship among them. The methodological framework does not include a deterministic trend in the cointegrating equation but includes a constant in the ECM. This approach is based on two main reasons:

Economic Justification: There are no artificial deterministic trends in Tunisia's macroeconomic variables such as GDP and ICT capital, hence equilibrium relationships should not be assumed to have deterministic trends.

Statistical Validity: The inclusion of a constant addresses the intrinsic linear trends in the series without biasing the estimation of the cointegrating vectors given that Tunisia's economy has undergone structural changes in the post-2011 era, including the expansion of ICT infrastructure and labor market reforms.

This framework helps to identify trend-agnostic stable relationships that are consistent with Tunisia's economic structure and its focus on digital transformation and inclusive growth in the post-revolution era.

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Table5:**JohansonCointegrationTest (Trace Statistic)**

Hypothesized No. ofCE(s)	Eigenvalue	Trace Statistic	5Percent CriticalValue	1Percent CriticalValue
None **	0.732991	88.34388	53.12	60.16
Atmost1**	0.598360	28.72964	34.91	41.07
Atmost2*	0.338221	15.36368	19.96	24.60
Atmost3	0.258662	8.978976	9.24	12.97

*(**)denotesrejection ofthehypothesisatthe5%(1%)level
Tracetestindicates1 cointegratingequation(s)atthe5%level
Tracetestindicates1 cointegratingequation(s)atthe1%level

The Johansen cointegration trace test reveals a statistically significant long-run equilibrium relationship between ICT development and economic growth in Tunisia over the period 1990–2023. The test results, structured around the hypothesis of "no cointegration," were rejected decisively at both the 5% and 1% significance levels. With a trace statistic of 88.34388—far exceeding the critical values of 53.12 (5%) and 60.16 (1%)—the analysis confirms at least one cointegrating relationship between the variables. Subsequent tests for "at most one cointegrating equation" produced a trace statistic of 28.72964, which falls below the critical thresholds of 34.91 (5%) and 41.07 (1%), indicating that Tunisia's economy and ICT sector share exactly one stable long-run relationship.

While weaker evidence for a second cointegrating relationship emerged at the 5% level (trace statistic: 15.36368 vs. critical value: 19.96), this result was not statistically robust at the 1% level. Tests for higher-order cointegration (at most two or three relationships) were conclusively rejected, reinforcing the primary finding of a single long-run equilibrium.

The presence of cointegration implies that ICT development and economic growth in Tunisia are intrinsically linked over the long term. Short-term deviations from this equilibrium—such as temporary fluctuations in ICT investment or GDP growth—will naturally correct over time, reflecting the enduring interdependence of these variables. This finding aligns with global empirical evidence that ICT acts as a catalyst for productivity, innovation, and structural economic transformation.

- Tunisia should prioritize sustained investment in ICT infrastructure, including broadband networks, digital literacy initiatives, and e-government platforms, to reinforce this long-run relationship.
- Sector-specific policies promoting ICT adoption in education, healthcare, and financial services could amplify growth synergies.
- Policymakers must account for the equilibrium-correction mechanism, ensuring short-term economic shocks do not derail long-term ICT-growth alignment.

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Table6: **Cointegrating Relation**

Normalized cointegrating coefficients				
LNGDP	**LNK_{ICT}**	**LNKNICT**	**LNL**	**C**
1.000000	2.541681	1.829309	14.13780	96.60031
	(2.83581)	(1.47199)	(8.79538)	(99.7706)

The estimated cointegrating relationship highlights a persistent long-term equilibrium among the variables, with LNGDP normalized to one. This normalization implies that the coefficients for LNKICT, LNKNICT, and LNL are expressed relative to LNGDP. The equation is given by:

$$LNGDP_t = 2.54 * LNK_{ICT} + 1.82 * LNK_{NTCT} + 14.13 * LNL + 96.6 + Z_t$$

This form illustrates that any change in LNKICT, LNKNICT, or LNL necessitates an offsetting adjustment in LNGDP to maintain the long-run balance. For instance, a one-unit increase in LNKICT, with all other factors held constant, requires LNGDP to adjust downward by about 2.54 units. A similar interpretation applies to the effects of LNKNICT and LNL, with each increment in these variables inducing a corresponding adjustment in LNGDP.

Although the coefficients in the normalized equation are positive, when the equation is restructured the adjustments they imply for LNGDP are negative. This means that any deviation from the equilibrium in LNKICT, LNKNICT, or LNL is ultimately counteracted by a change in LNGDP, ensuring that the long-term relationship remains stable.

Accompanying the coefficients are their standard errors—2.83581 for LNKICT, 1.47199 for LNKNICT, 8.79538 for LNL, and 99.7706 for the constant term. These standard errors indicate the precision of the estimates, and in cases where the error is large relative to the coefficient (as with LNKICT), it suggests a degree of uncertainty in the exact magnitude of the effect. This aspect is crucial when evaluating the statistical significance of the relationships.

Overall, this cointegration analysis reveals that despite short-term fluctuations, LNGDP, LNKICT, LNKNICT, and LNL are bound by a robust long-term equilibrium. The interconnectedness of these variables implies that shocks affecting one element will, over time, be balanced by adjustments in LNGDP. Such insights are vital for understanding the structural linkages within the economy and can inform policy decisions aimed at achieving long-term economic stability.

While the test confirms a cointegrating relationship, it does not quantify the magnitude or directionof ICT's impact on growth. A **Vector Error Correction Model (VECM)** would be necessary to estimate short-term dynamics and long-term adjustment speeds.

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Tableau 7: **Error Correction Model Estimation**

Error Correction:	**D(LNGDP)**	**D(LNK_{ICT})**	**D(LNK_{NICT})**	**D(LNL)**
CointEq1	-0.052549	-0.031309	-0.083739	-0.099220
	[-2.15299]	[-9.13186]	-2.22638]	[-3.18568]
D(LNGDP(-1))	0.024547	1.332601	0.034591	0.003834
	[2.06760]	[6.64858]	[0.16934]	[0.15291]
D(LNGDP(-2))	0.026312	0.870877	-0.049830	-0.037300
	[1.88483]	[5.08635]	[-0.28557]	[-1.74170]
D(LNK_{ICT}(-1))	-0.200106	0.716519	0.195350	0.031713
	[1.96371]	[7.76075]	[2.07619]	[2.74613]
D(LNK_{ICT}(-2))	-0.144423	0.723156	-0.067777	0.005083
	[-2.51860]	[4.70441]	[-0.43265]	[0.26437]
D(LNK_{NICT}(-1))	0.463676	-0.261569	0.485254	0.093662
	[0.77528]	[-0.79232]	[1.44233]	[2.26825]
D(LNK_{NICT}(-2))	-0.280989	0.881725	0.150709	0.091182
	[-0.44251]	[2.51560]	[0.42191]	[2.07984]
D(LNL(-1))	1.140015	0.453834	0.370145	-0.648714
	[0.39961]	[1.88820]	[0.23065]	[-3.29357]
D(LNL(-2))	0.885327	2.796778	-0.030273	-0.314490
	[0.33998]	[1.94572]	[-0.02067]	[-1.74921]
C	0.067231	-0.645500	0.030742	0.010042
	[0.46662]	[-8.11642]	[0.37930]	[1.00948]
R-squared	0.899139	0.899211	0.850755	0.889459
Adj. R-squared	0.860883	0.843217	0.767841	0.852492
Sumsq. resids	0.025354	0.007725	0.008023	0.000121
S.E.equation	0.037531	0.020716	0.021112	0.002591
F-statistic	1.793813	16.05912	10.26068	4.189196
Loglikelihood	60.96157	78.19432	77.64526	138.4795
AkaikeAIC	-3.445626	-4.634091	-4.596225	-8.791689
SchwarzSC	-2.926996	-4.115461	-4.077596	-8.273059
Meandependent	0.101278	0.132780	0.114850	0.025098
S.D.dependent	0.042519	0.052320	0.043817	0.003790

The results of the error correction model (ECM) provide a comprehensive understanding of how Tunisia's economy responds to short-run fluctuations while gradually converging toward long-run equilibrium. At the core of this model lies the error correction term **(CointEq1)**, which quantifies the speed at which deviations from equilibrium are corrected over time. The negative and statistically significant coefficients across all variables confirm that when the economy experiences shocks, these variables adjust systematically to restore stability. Specifically, the coefficient for LNGDP (-0.052549, t = -2.15299) suggests that approximately 5.3% of any disequilibrium in GDP is corrected in the following period. This moderate adjustment speed indicates that while GDP responds to imbalances, the correction is gradual, reflecting the inertia typically associated with economic output. Similarly, the correction mechanism for LNKICT (-0.031309, t = -9.13186) demonstrates that technological advancements, such as ICT adoption, contribute to the realignment of economic conditions, with about 3.1% of any deviation being corrected per period. The statistical significance of this result implies that ICT plays a crucial role in stabilizing Tunisia's economy by mitigating imbalances efficiently.

On the other hand, LNKNICT (-0.083739, t = -2.22638) exhibits a relatively higher adjustment speed, with 8.4% of deviations corrected each period. This suggests that non-ICT-related factors respond more aggressively to economic shocks, possibly due to their higher sensitivity to structural changes or external influences. Meanwhile, LNL (-0.099220, t = -3.18568) shows the most pronounced correction speed at 9.9%, indicating that factors related to labor and land exhibit a more substantial response

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in restoring equilibrium. However, despite its statistical significance, this relatively higher adjustment rate could also indicate volatility in labor market dynamics or structural shifts that require continuous adaptation. The presence of lagged differences in the model further highlights the short-term persistence and dynamic interactions among these variables. For instance, LNGDP (-1) (0.024547, t = 2.06760) suggests that past GDP growth positively influences current GDP changes, reinforcing economic inertia and suggesting that previous growth trends continue to shape present economic conditions. Similarly, the lagged term for LNKICT (-1) (0.716519, t = 7.76075) underscores the lasting impact of past ICT investments, implying that technological advancements do not yield immediate effects but instead generate persistent benefits over multiple periods.

Moreover, the overall goodness of fit, as indicated by the high R-squared values (ranging from 0.85 to 0.90), suggests that the model successfully captures a significant proportion of the variations in the dependent variables. However, the adjusted R-squared values, while also high, reveal that some room for improvement remains, particularly for the LNKNICT equation, where additional explanatory variables or structural refinements might enhance predictive accuracy. These results underscore the critical role of GDP and ICT in Tunisia's economic adjustments, as both exhibit significant short-run and long-run correction mechanisms. While LNKNICT demonstrates a more rapid adjustment to disequilibrium, LNL follows a relatively more gradual correction path, possibly due to labor market rigidities or other institutional factors. The insights derived from this ECM analysis are essential for policymakers, as they highlight the need for targeted interventions in areas where adjustments are slower, particularly in ICT and labor-related sectors. By understanding how these variables interact and respond to economic shocks, policymakers can design strategic policies to enhance resilience, ensure macroeconomic stability, and foster sustained economic growth over time.

VII. LIMITATIONS AND RECOMMENDATIONS

As with any research, this work is not without its limitations and constraints, and for that reason we were able to discuss the limitations and constraints of the study in terms of results, and provide recommendations for policy makers on how best to use new information and communication technologies.

The first limitation has to do with the results of the statistical analysis of the growth accounting type that can be achieved. In this regard, the impact of ICT on economic growth may be confounded with that of other factors: environment, national economic policies (structural reforms), etc… Furthermore, macroeconomic studies are characterized by specific problems of estimation and specification. They are based on several important assumptions made necessary by the lack of data, which also makes the crucial issue of harmonization of methods for international comparisons.

The second limitation has to do with the Tunisian system of national accounts, which has been greatly revised but is still outdated due to the changing technologies and the economic and social structure of businesses. Therefore, there is a need for further revision of this system in order to capture more effectively the ICT goods and services. This review will cover both the structuring principles of the bill, the relationship between the classifications of activities, product classifications and customs classifications, the creation of new sections and divisions, the distinction between the divisions and the formation of elementary classes. This is because it is important to further breakdown the added value of GFCF by sector.

It can be argued that government action could help to accelerate the decline in investment costs of new technologies, the adoption of a policy of active competition and measures to promote open markets, both internally and externally. However, it should be noted that investment in ICTs and their diffusion does not only depend on the cost of capital goods themselves, but also on the related costs of communication and use, once the equipment is connected to a network. And the development of competition in the telecommunications industry through deep regulatory reform has a special significance for reducing these costs.

Policies should take more into account the needs and specificities of the services sector to promote growth. Competition and business dynamism in many service sectors remain limited by regulatory barriers, which dampen the intensity of market selection on firms' innovation performance. Furthermore, some specific regulations may hinder the development of new ICT. applications and the capability of firms to

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exploit them and, therefore, further regulatory reforms are required to support competition and innovation and to reduce barriers and administrative procedures for new market entrants and new firms.

VIII. CONCLUSION

Information and communication technologies appear to be in line with the changes that have taken place in the different economies. Indeed, these technologies have considerable effects on the quality of goods and services and productive efficiency, which are accredited to supporting a stable and sustainable path of growth in the U.S. economy. Many economists and theorists attribute the significance of the role in today's economic growth to sectors that are identified as the "new economy" in ICT. The positive impacts of ICT exist, and are mainly felt in OECD countries, thus raising a lot of interest on the importance of these production factors in a small emerging economy, such as Tunisia. To analyze these possibilities, we seek to establish the causal relationship between Tunisian ICT and economic growth as the first aim of this paper.

We started by reviewing the plenty of theoretical work that has been written on the subject first. Then we reviewed the impact of telecommunications in Tunisia over the past decade. The present survey suggests that Tunisia has an advantage in the development of the ICT industry which is based on the development of a solid fixed and mobile telephone infrastructure.

Last, we examined the relation between economic growth and ICT using the neoclassical model as a theoretical framework, and specifically the Cobb Douglas production function. The usual tests (unit root tests) were applied on the economic series of the study and all variables were found to be non-stationary (integrated of order 1). Consequently, we could attempt to discover a long-term relationship among the series studied, as to prove it, we employed the Johansen cointegration test on the explanatory variables. The results of the study show that there is a long-run relationship between economic growth (GDP) and ICT (investments) in the telecommunications sector, but the results of these estimations are restricted because the explanatory variable, ICT capital, is measured by investment in the telecommunications sector, thus the findings are related to the contribution of that sector only.

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