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UNIVERSITY OF BUEA
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Tel: (+237) 33354691 – Fax: (+237) 33354692
Email: editor@jtis-htttcubuea.com
Website: https://www.jtis-htttcubuea.com

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Human Capital, Technological Catch-up, and Growth Divergence in Sub-Saharan Africa: A Moderated-Mediation Analysis of Underemployment and Technology Adoption

Dr. Eyong Ako
The University of Bamenda, Northwest Region, Cameroon
School: Higher Institute of Commerce and Management,
Department: Organisational Sciences,
E-mail: akorolly87@yahoo.com

ORCID Id: https://orcid.org/0009-0005-8689-6788

Njie Immaculate Lum
mmaculatelum71@gmail.com
Department of Money and Banking
Higher Institute of Commerce and Management
The University of Bamenda

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Ab**stract**

This study investigates the mechanisms through which human capital influences economic growth in Sub-Saharan Africa (SSA), with particular focus on technological catch-up as a mediator and underemployment as a moderator of the human capital-growth relationship. Motivated by persistent growth divergence across SSA countries despite decades of human capital investment, the study addresses five objectives: quantifying the human capital-growth relationship, testing underemployment as a conditional constraint, evaluating technology adoption as a transmission channel, analysing sub-regional heterogeneity in catch-up dynamics, and distinguishing short-run from long-run adjustment processes. The study employs a quantitative longitudinal panel design using secondary data from World Bank WDI, Penn World Table, ILO ILOSTAT, and World Governance Indicators covering 2000-2025. The sample comprises 35 SSA countries (875 observations) distributed across four economic blocs: ECOWAS (10), EAC (7), SADC (10), and ECCAS (6). Data analysis techniques include fixed effects regression with Driscoll-Kraay standard errors, moderation analysis with interaction terms, mediation analysis following Baron and Kenny (1986), sub-regional analysis using seemingly unrelated estimation, and ARDL-Pooled Mean Group estimation to distinguish short-run from long-run dynamics. The results reveal that human capital positively affects growth, with a one-unit increase in the Human Capital Index associated with 3.18 percentage points higher annual growth, consistent with Nelson-Phelps catch-up predictions. Underemployment significantly moderates this relationship, reducing the marginal effect from 5.68 at zero underemployment to 2.32 at 40% underemployment, indicating that labour underutilization is a binding constraint on catch-up growth. Technology adoption mediates 44.8% of human capital's effect on growth, confirming that human capital facilitates growth primarily through enhancing technological catch-up capacity. Significant growth divergence exists across sub-regions: ECOWAS shows no significant catch-up effect (coefficient 2.15, $p > 0.10$) while EAC (4.32, $p < 0.05$) and SADC (4.85, $p < 0.05$) exhibit strong effects, explaining persistent growth divergence within SSA. Long-run effects exceed short-run effects by a factor of 4.7, with an error correction term of -0.32 indicating rapid adjustment to long-

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run equilibrium catch-up trajectories. The study concludes that human capital investment alone is insufficient for catch-up growth in SSA; underemployment must be addressed as a binding constraint, technology adoption requires coordinated policy attention, and sub-regional growth divergence demands tailored rather than uniform policy approaches. Recommendations include implementing labour market information systems to reduce skill mismatches, prioritizing learning quality over access expansion, coordinating human capital investment with technology and infrastructure policies, adopting graduate tracking systems following Rwanda's model, and targeting structural reforms in ECOWAS to improve the growth responsiveness of its large labour force to human capital accumulation.

Keywords: Human capital, economic growth, underemployment, technology adoption, Sub-Saharan Africa, panel data

1. Introduction

Human capital development the enhancement of knowledge, skills, and health embodied in individuals represents a fundamental driver of long-term economic growth (Schultz, 1961; Becker, 1964; Lucas, 1988). The theoretical proposition that investments in education and health generate productivity gains and facilitate technological adoption has shaped development policy globally. However, the translation of human capital into growth outcomes varies dramatically across regions, with Sub-Saharan Africa (SSA) presenting the most consequential case.

Sub-Saharan Africa is experiencing the fastest working-age population expansion globally, projected to reach 2.2 billion by 2050. This demographic trajectory presents both an unprecedented opportunity for a demographic dividend and a profound risk if human capital development fails to keep pace. Currently, the World Bank's Human Capital Index for SSA averages approximately 0.40, meaning a child born in the region can achieve only 40% of their potential productivity (World Bank, 2025). More than one in five youth across Africa are neither in education nor working, and foundational learning outcomes remain critically low.

Despite theoretical consensus on human capital's importance, Sub-Saharan Africa faces a paradoxical situation: a rapidly expanding workforce combined with persistently low human capital investment and questionable returns on existing investments. Several interconnected problems emerge.

First, the magnitude of human capital's effect on growth in SSA requires updating with post-pandemic data (Chancel et al., 2026). Second, the transmission mechanisms through which human capital affects growth in SSA's unique structural context characterized by underemployment exceeding 21% and reaching over 40% in some countries (Atake et al., 2025) remain poorly understood. Third, a critical skills mismatch exists between educational outputs and labour market demands, resulting in "jobless growth" where GDP increases fail to translate into employment gains. Fourth, substantial heterogeneity across SSA sub-regions (ECOWAS, EAC, SADC, ECCAS) suggests that aggregate analyses mask important variation (Keji et al., 2024). Fifth, underemployment significantly moderates the human capital-growth relationship, yet this interaction remains underexplored. The primary objective is to examine the effects of human capital development on economic growth in

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Sub-Saharan Africa, accounting for the moderating role of underemployment and the mediating role of technological adoption with the Specific objectives: To quantify the relationship between human capital indicators and economic growth in SSA countries from 2000 to 2025.To analyse the moderating effect of underemployment on the human capital-growth relationship. To evaluate the mediating role of technology adoption in transmitting human capital effects to growth. To compare the effects of human capital on growth across SSA sub-regional economic blocs. To assess the short-run versus long-run dynamics of human capital effects.

2. Literature Review

2.1 Conceptual Literature

The Concept of Human Capital

Human capital refers to the stock of knowledge, skills, health, and abilities embodied in individuals that enables productive economic activity (Schultz, 1961). The concept fundamentally transformed economic analysis by recognizing that people are a form of capital an asset in which investment yields future returns (Becker, 1964). Contemporary conceptualization recognizes human capital as multidimensional, encompassing four primary components.

Cognitive skills represent the foundational abilities of literacy, numeracy, problem-solving, and critical thinking (Hanushek & Woessmann, 2015). These skills enable individuals to process information, learn new tasks, adapt to changing workplace demands, and make informed decisions (World Bank, 2018). Cognitive skills are primarily developed through formal education systems, though family environment and early childhood experiences play crucial roles (Heckman, 2006). The quality of cognitive skills what individuals actually know and can-do matters more than the quantity of schooling completed (Pritchett, 2013).

Non-cognitive or socio-emotional skills include resilience, teamwork, communication, adaptability, work ethic, and self-regulation (Heckman & Kautz, 2012). These skills are increasingly recognized as critical for labour market success, particularly in service-oriented economies where interpersonal interactions are central to production (Borghans et al., 2008). Non-cognitive skills are developed through family socialization, peer interactions, and structured activities including sports, arts, and community service (Cunha & Heckman, 2008). Evidence from labour economics demonstrates that non-cognitive skills predict earnings and employment outcomes independently of cognitive skills (Lindqvist & Vestman, 2011).

Health capital encompasses physical and mental health status, nutritional adequacy, freedom from disease, and life expectancy (Grossman, 1972). Health affects both the capacity to work (labour supply through reduced morbidity and mortality) and productivity while working (labour quality through cognitive function and physical energy) (Bloom, Canning, & Sevilla, 2004). The complementarity between health and

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education is strong: healthier children learn more effectively (Miguel & Kremer, 2004), and educated parents invest more in children's health (Currie & Moretti, 2003). This complementarity generates multiplier effects where investments in one dimension enhance returns to investments in the other (Strauss & Thomas, 1998).

Technical and vocational skills refer to occupation-specific competencies relevant to particular industries or job functions (Eichhorst et al., 2015). These skills are typically acquired through technical and vocational education and training (TVET) systems, apprenticeships, or on-the-job training (Autor, 2015). Unlike general cognitive skills, technical skills have shorter relevance horizons as technologies and production processes evolve (Deming, 2017). This creates ongoing needs for reskilling and upskilling throughout working lives (World Economic Forum, 2020).

The Concept of Economic Growth

Economic growth is conventionally conceptualized as the increase in the inflation-adjusted market value of goods and services produced by an economy over time (Barro & Sala-i-Martin, 2004). The most common operationalization is growth in real Gross Domestic Product (GDP) per capita, which accounts for both output expansion and population changes (Acemoglu, 2009). This measure captures improvements in average living standards, though it does not directly address distributional concerns (Stiglitz et al., 2010).

Contemporary growth analysis distinguishes among three related but distinct concepts (World Bank, 2025). **Output growth** refers to the raw increase in GDP, which can occur through population growth, increased labour force participation, capital accumulation, or productivity improvements (Solow, 1956). **Productivity growth** output per unit of input (labour or capital) represents efficiency gains that drive sustainable increases in living standards (Krugman, 1994). Productivity growth is the fundamental source of long-run prosperity (Easterly & Levine, 2001). **Inclusive growth** refers to growth that reduces poverty and inequality while expanding employment (Ranieri & Ramos, 2013). For Sub-Saharan Africa, the distinction is critical because the region exhibits "jobless growth" GDP increases without commensurate employment expansion (World Bank, 2025; Atake et al., 2025) suggesting that productivity effects from human capital may not be fully realized (Fox & Thomas, 2016).

The Human Capital-Growth Nexus: Conceptual Pathways

The conceptual relationship between human capital and economic growth operates through three primary pathways that interact and reinforce each other (Lucas, 1988; Romer, 1990).

Direct productivity pathway: More skilled workers produce more output per unit time, directly increasing GDP (Mankiw, Romer, & Weil, 1992). This effect operates at both the individual level (educated workers earn higher wages) (Card, 1999) and the aggregate level (average skill levels correlate with average productivity) (Barro, 2001). The direct pathway includes not only the quantity of work but also the quality skilled workers make fewer

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errors, require less supervision, and can perform more complex tasks (Autor et al., 2003). This pathway is immediate and does not require changes in technology or organizational structure, though its magnitude is amplified by complementary factors (Goldin & Katz, 2008).

Technological adoption pathway: Human capital enhances the capacity to adopt, adapt, and innovate new technologies (Nelson & Phelps, 1966). Countries with higher human capital levels can narrow productivity gaps with technological leaders more rapidly because skilled workers can understand, implement, and improve upon existing technologies from frontier economies (Benhabib & Spiegel, 1994). This pathway is captured conceptually by the "distance to the technology frontier" concept the gap between a country's productivity level and global best practice (Aghion & Howitt, 2005). For countries far from the frontier, human capital investments yield returns primarily through imitation and adaptation rather than frontier innovation (Acemoglu et al., 2006).

Spillover and complementarity pathway: Human capital generates positive externalities that extend beyond the individual worker (Moretti, 2004). Educated workers improve the productivity of those around them through knowledge sharing, mentoring, and demonstration effects (Rauch, 1993). Additionally, human and physical capital are complementary skilled workers make capital investments more productive because they can operate sophisticated machinery, maintain equipment properly, and identify opportunities for process improvement (Griliches, 1969). This complementarity means that human capital investment raises the returns to physical capital investment, creating virtuous cycles of accumulation (Redding, 1996).

2.2 Theoretical Literature

Human Capital Theory (Schultz, 1961; Becker, 1964)

In his presidential address to the American Economic Association, Schultz (1961) fundamentally challenged the prevailing view that labour was a homogeneous factor of production. His seminal paper "Investment in Human Capital" argued that expenditures on education, health, and migration are not merely consumption but investments that enhance productive capacity (Schultz, 1961). Schultz demonstrated that a substantial portion of economic growth could not be explained by increases in physical capital or labour quantity, leading him to attribute this residual to improvements in labour quality human capital (Schultz, 1961).

Schultz identified five major categories of human capital investment: (1) health facilities and services affecting life expectancy, strength, and vitality; (2) on-the-job training including apprenticeships; (3) formal education at primary, secondary, and tertiary levels; (4) adult education and extension programs; (5) migration of individuals to adapt to changing job opportunities (Schultz, 1961). He emphasized that human capital is not static but can be augmented through deliberate investment decisions, and that the returns to these

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investments could be estimated using the same tools developed for physical capital analysis (Schultz, 1961).

Schultz's key contribution was methodological: he provided the framework for calculating rates of return to education by comparing the earnings of individuals with different schooling levels, adjusted for ability and other factors (Schultz, 1961). This rate-of-return approach became the dominant empirical method in the economics of education for decades (Psacharopoulos & Patrinos, 2018). Schultz also highlighted that human capital investment decisions are influenced by expectations of future returns, and that credit constraints—particularly for poor families—could lead to underinvestment from a social perspective, justifying public intervention (Schultz, 1961).

Becker's treatise "Human Capital: A Theoretical and Empirical Analysis with Special Reference to Education" systematized and extended Schultz's insights into a rigorous theoretical framework (Becker, 1964). Becker developed a formal model of human capital investment where individuals choose optimal levels of education and training by comparing marginal benefits (higher future earnings) to marginal costs (direct expenses plus foregone earnings) (Becker, 1964). He introduced the concept of "on-the-job training" as a form of human capital accumulation, distinguishing between general training (useful at many firms) and specific training (useful only at the current firm) (Becker, 1964).

Becker's key theoretical contribution was demonstrating that in competitive labour markets, firms will not pay for general training because workers would capture the returns by moving to other firms (Becker, 1964). This implies that workers should bear the costs of general training, which explains why individuals invest in their own education (Becker, 1964). For specific training, firms and workers share costs and returns because the training loses value if the employment relationship ends (Becker, 1964). This framework remains the standard for analysing firm-sponsored training (Autor, 2001).

Becker also contributed empirically, estimating rates of return to education for the United States and demonstrating that returns were substantial on the order of 10-15% annually comparable to or exceeding returns to physical capital (Becker, 1964). He showed that returns were higher for more educated individuals, higher for younger workers (who have longer to recoup investments), and varied across occupations and industries (Becker, 1964). Becker's work provided the empirical foundation for the widespread view that human capital is a critical determinant of earnings and productivity (Card, 1999).

Application to Sub-Saharan Africa: Human capital theory predicts that SSA countries, which have very low average education levels, should experience high returns to additional education investments (Psacharopoulos & Patrinos, 2018). However, the theory also suggests that credit constraints are particularly binding in SSA, where capital markets are underdeveloped and poverty limits families' ability to invest in children's education (World Bank, 2018). This justifies public subsidies and social protection programs that enable poor families to keep children in school (Glewwe & Muralidharan, 2016). The theory also implies

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that as SSA economies grow and labour markets develop, the returns to education should increase as skill-intensive industries expand (Autor, 2014).

Endogenous Growth Theory (Lucas, 1988; Romer, 1990)

Lucas's paper "On the Mechanics of Economic Development" transformed growth theory by incorporating human capital into the core of the growth process (Lucas, 1988). In the neoclassical Solow model that dominated prior thinking, growth is driven by exogenous technological progress that occurs independently of economic decisions (Solow, 1956). This implies that poor countries should converge to rich countries because diminishing returns to physical capital make investment more profitable in capital-scarce economies (Barro & Sala-i-Martin, 2004). Lucas observed that convergence was not occurring for many poor countries, particularly in Africa and Latin America, suggesting that something was missing from the model (Lucas, 1988).

Lucas introduced human capital as a factor that could generate sustained growth without relying on exogenous technology (Lucas, 1988). In his model, individuals choose how to allocate time between current production and human capital accumulation (education, training, learning-by-doing) (Lucas, 1988). The key departure from neoclassical models is that human capital does not face diminishing returns at the aggregate level because knowledge spillovers learning from others create increasing returns (Lucas, 1988). When individuals invest in their own human capital, they increase not only their own productivity but also the productivity of others through knowledge diffusion, mentorship, and shared learning environments (Lucas, 1988).

Lucas also contributed the concept of "learning-by-doing" as a mechanism for human capital accumulation without formal schooling (Lucas, 1988). As workers produce goods, they become more skilled through experience, and these skills then apply to future production (Arrow, 1962). Learning-by-doing is particularly relevant for SSA's large informal sector, where much skill formation occurs through apprenticeship and on-the-job training rather than formal education (Fox & Thomas, 2016).

Romer's paper "Endogenous Technological Change" shifted focus from human capital as a direct factor of production to human capital as an input into innovation and technology adoption (Romer, 1990). In the Romer model, long-run growth is driven by the discovery of new ideas non-rival goods that can be used by many people simultaneously without depletion (Romer, 1990). The production of new ideas depends on the stock of human capital engaged in research and development (R&D) (Romer, 1990).

The Romer model implies that countries with larger stocks of human capital particularly scientists, engineers, and skilled workers engaged in R&D will generate faster technological progress and therefore faster growth (Romer, 1990). For countries far from the technology frontier, the relevant mechanism is adoption rather than innovation: human capital facilitates the transfer, adaptation, and implementation of technologies developed elsewhere (Howitt, 2000). This requires not only top-tier scientists but also technicians,

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managers, and skilled workers who can operate and maintain imported technologies (Aghion & Howitt, 2005).

Application to Sub-Saharan Africa: Endogenous growth theory suggests that SSA's low human capital levels are both a cause and a consequence of slow growth (Easterly & Levine, 1997). The poverty trap logic implies that temporary but substantial investments in human capital could shift the region onto a higher growth trajectory (Sachs et al., 2004). The theory also suggests that SSA countries far from the technology frontier may benefit more from policies that facilitate technology transfer such as attracting FDI, importing capital goods, and building technical skills than from policies that promote frontier innovation (Acemoglu et al., 2006). This is not to say that innovation is irrelevant, but that imitative strategies may yield higher short-run returns given the large distance to the frontier (Rodrik, 2016).

Nelson-Phelps Catch-up Theory (1966)

Richard Nelson and Edmund Phelps (1966) proposed a distinctive perspective on human capital and growth that diverges from both the Schultz-Becker human capital model and the Lucas-Romer endogenous growth framework (Nelson & Phelps, 1966). Their paper "Investment in Humans, Technological Diffusion, and Economic Growth" argued that the primary contribution of human capital to growth is not through directly increasing output but through facilitating the adoption and diffusion of new technologies (Nelson & Phelps, 1966).

The Nelson-Phelps model is formally expressed as:

$$dA/dt = \varphi(H) \times (A - A)^*$$

Where dA/dt is the rate of productivity growth, A is current productivity, A* is the technology frontier (maximum possible productivity given available knowledge), and φ(H) is a function of human capital that determines the speed of catch-up (Nelson & Phelps, 1966). The key prediction is that the growth rate of productivity is increasing in the gap between current and frontier productivity, and also increasing in the stock of human capital (Nelson & Phelps, 1966).

Application to Sub-Saharan Africa: The Nelson-Phelps model is particularly relevant for SSA because the region is far from the technology frontier and faces substantial adoption challenges (World Bank, 2025). The model predicts that SSA countries could achieve rapid catch-up growth if they invest in human capital while simultaneously opening to technology transfer (Rodrik, 2016). However, the model also suggests that low human capital levels are a binding constraint on adoption: even if technologies are available, the workforce may lack the skills to implement them productively (Bloom, Canning, & Chan, 2006). This creates a coordination problem where technology and human capital must be developed together, not sequentially (Hausmann & Rodrik, 2003).

Schumpeterian Growth Theory (Aghion & Howitt, 1992, 2005)

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Philippe Aghion and Peter Howitt developed Schumpeterian growth theory, which integrates Joseph Schumpeter's concept of "creative destruction" the process by which new innovations displace old technologies and firms into formal growth modelling (Aghion & Howitt, 1992). Their 1992 paper "A Model of Growth through Creative Destruction" established the framework, and their 2005 "Handbook of Economic Growth" chapter provided a comprehensive synthesis (Aghion & Howitt, 2005).

The Schumpeterian model differs from both the Lucas and Nelson-Phelps approaches in its emphasis on the innovation process itself (Aghion & Howitt, 1992). A key insight of Schumpeterian theory is the distinction between **frontier growth** (innovation at the technology frontier) and **catch-up growth** (imitation by countries behind the frontier) (Aghion & Howitt, 2005). For countries at the frontier, growth is driven by innovation, which requires high-skilled workers engaged in R&D and a supportive institutional environment (patent protection, research universities, venture capital) (Aghion, Harris, & Vickers, 1997). For countries behind the frontier, growth is driven by imitation—adopting technologies already developed elsewhere which requires a different set of skills and institutions (Aghion & Howitt, 2005).

Application to Sub-Saharan Africa: Schumpeterian theory suggests that most SSA countries are sufficiently far from the technology frontier that catch-up strategies imitation and adaptation of existing technologies should dominate their growth policies (Rodrik, 2016). This implies a focus on engineering, technical, and managerial skills rather than basic research (Bloom et al., 2006). However, the theory also suggests that as countries develop and approach the frontier, they will need to shift their human capital strategies (Aghion & Howitt, 2005). This is a long-run consideration, as SSA's distance to the frontier remains substantial, but forward-looking policies can anticipate the need for eventual transition (Acemoglu et al., 2006).

2.3 Empirical Literature

The most comprehensive recent evidence comes from this global historical study published in the *Journal of Public Economics* (Chancel et al., 2026). The authors constructed a new database on public expenditure and revenue covering all world regions from 1800 to 2025, with particular attention to education and health expenditure (Chancel et al., 2026). Their dataset includes 48 countries plus 9 residual regions, providing unprecedented historical depth and geographic coverage (Chancel et al., 2026).

The authors developed new methods for adjusting public expenditure for age structure, recognizing that spending on children (who are not in the labour force) has different growth implications than spending on working-age adults (Chancel et al., 2026). Their age-adjusted human capital expenditure measure is superior to raw expenditure-to-GDP ratios used in previous studies (Chancel et al., 2026). Using panel regressions with country and region-period fixed effects, they estimate that one additional percentage point of GDP in age-adjusted human capital expenditure increases the annual productivity growth rate by an average of 0.1 percentage points (Chancel et al., 2026).

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This study examined the empirical relationship between human capital and economic growth across eight SSA countries (Egypt, Sudan, Algeria, Morocco, Tunisia, Mauritania, Somalia, Djibouti) from 1990 to 2022, though their geographic scope is primarily North-East Africa with some SSA countries (Elsharif et al., 2024). They employed the pooled mean group (PMG) estimator within a panel autoregressive distributed lag (ARDL) approach, which is appropriate for panels with mixed orders of integration (Elsharif et al., 2024).

The authors made methodological contributions by using the PMG estimator, which constrains long-run coefficients to be equal across countries while allowing short-run coefficients to vary (Elsharif et al., 2024). This is appropriate when theory suggests a common long-run relationship but country-specific adjustment dynamics (Pesaran et al., 1999). Their long-run analysis demonstrates that human capital positively influences economic growth, with a one-unit increase in secondary school enrolment resulting in a 0.184% increase in economic growth under their mixed effects model (Elsharif et al., 2024). Primary school enrolment is associated with a 0.117% increase (Elsharif et al., 2024).

This master's thesis at the University of Béjaia investigated human capital, technology frontier distance, and economic growth in 16 SSA countries from 1990 to 2019 (Kalonga & Katusiime, 2024). The study applies the theoretical framework of Nelson and Phelps (1966) and Aghion et al. (2005), hypothesizing that economic growth is influenced by the interaction between education levels (measured as average years of schooling) and distance to the technology frontier (ibid).

The authors constructed a measure of distance to the technology frontier using GDP per capita relative to the United States (the frontier economy) and tested whether the growth effect of human capital is larger for countries farther from the frontier (Kalonga & Katusiime, 2024). Their empirical results support the Nelson-Phelps hypothesis: the coefficient on the interaction between education and distance to frontier is positive and significant, indicating that human capital has larger growth effects when the technology gap is larger (ibid).

The research documents that SSA countries face significant challenges in adopting advanced technologies due to limited skilled labour forces, in contrast to developed countries that use high technology and human capital more effectively in production processes (Kalonga & Katusiime, 2024). They provide country-level examples: South Africa, with relatively higher human capital, has been able to adopt more sophisticated technologies in mining and finance, while countries like Niger and Chad, with very low human capital, remain almost entirely reliant on traditional agricultural technologies (ibid).

2.4 Literature Gap

Existing studies using panel data have predominantly used traditional estimators without fully accounting for cross-sectional dependence and slope heterogeneity. Most studies have examined linear relationships without testing for nonlinearities or threshold effects. Previous research has typically used single human capital proxies rather than composite

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indices. The COVID-19 pandemic and subsequent disruptions have fundamentally altered the context. Learning losses during school closures, changes in labour demand patterns, and accelerated digital transformation create new dynamics not captured by studies ending in 2019. The rapid expansion of remote work and digital services particularly in Nigeria's Business Process Outsourcing industry represents structural shifts requiring updated analysis.

3. Methodology

The study adopts a **quantitative longitudinal panel design** is employed, tracking multiple countries over time to control for unobserved country-specific heterogeneity and to distinguish short-run from long-run effects (Wooldridge, 2010). Secondary data are drawn from five internationally recognized sources:

Data Source	**Variables**	Period
Penn World Table (PWT) version 10.1	Capital stock, human capital index, total factor productivity	2000-2024
World Bank Human Capital Index (HCI)	Composite human capital (survival, schooling, learning-adjusted years, health)	2010-2024
International Labour Organization (ILO)	Underemployment rates, labour force participation	2000-2025
World Governance Indicators (WGI)	Institutional quality (six dimensions averaged)	2000-2024

The study covers **35 Sub-Saharan African countries** from **2000 to 2025**, Captures pre-pandemic, pandemic, and post-pandemic dynamics yielding a maximum of **875 observations** (35 countries × 25 years). Countries are distributed across four sub-regional economic blocs: **ECOWAS (West Africa):** 10 countries (Nigeria, Ghana, Côte d'Ivoire, Senegal, Benin, Burkina Faso, Mali, Guinea, Togo, Liberia) **EAC (East Africa):** 7 countries (Kenya, Tanzania, Uganda, Rwanda, Ethiopia, Burundi, South Sudan) **SADC (Southern Africa):** 10 countries (South Africa, Angola, Zambia, Zimbabwe, Mozambique, Malawi, Botswana, Namibia, Lesotho, Eswatini) **ECCAS (Central Africa):** 6 countries (DRC, Cameroon, Gabon, Republic of Congo, Chad, CAR) . Countries with more than five years of missing data for key variables are excluded.

Econometric Models

Baseline Model (Objective 1)

$$GROWTH\_it = \alpha + \beta_1 HCI\_it + \beta_2 ENROLL\_SEC\_it + \beta_3 ED\_ATTAIN\_it + \beta_4 LE\_it + \beta_5 INV\_it + \beta_6 LABOR\_it + \beta_7 TRADE\_it + \beta_8 FDI\_it + \beta_9 INST\_it + \beta_{10} INF\_it + \mu\_i + \lambda\_t + \varepsilon\_it$$

Where:

- i = country (1...35)

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- t = year (2000...2025)
- μ_i = country fixed effects
- λ_t = time fixed effects
- ε_{it} = idiosyncratic error term

Moderation Model (Objective 2)

$$GROWTH_{it} = \alpha + \beta_1 HCI_{it} + \beta_2 UNDEREMP_{it} + \beta_3 (HCI_{it} \times UNDEREMP_{it}) + \beta_4 CONTROLS_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

A negative and significant β_3 supports the hypothesis that underemployment diminishes the human capital effect.

Mediation Model (Objective 3)

Following Baron and Kenny (1986):

- **Step 1 (Direct effect):** $GROWTH_{it} = \alpha + \gamma_1 HCI_{it} + CONTROLS_{it} + \mu_i + \lambda_t + \varepsilon_{it}$
- **Step 2 (Effect on mediator):** $TECH_{it} = \alpha + \delta_1 HCI_{it} + CONTROLS_{it} + \mu_i + \lambda_t + \varepsilon_{it}$
- **Step 3 (Mediated effect):** $GROWTH_{it} = \alpha + \gamma'_1 HCI_{it} + \rho_1 TECH_{it} + CONTROLS_{it} + \mu_i + \lambda_t + \varepsilon_{it}$

Mediation is established if γ_1, δ_1, and ρ_1 are significant and $\gamma'_1 < \gamma_1$.

Sub-Regional Heterogeneity Model (Objective 4)

Separate estimation for each bloc (r = ECOWAS, EAC, SADC, ECCAS):

$$GROWTH_{rit} = \alpha_r + \beta_{r1} HCI_{rit} + \beta_{r2} ENROLL\_SEC_{rit} + CONTROLS_{rit} + \mu_{ri} + \lambda_{rt} + \varepsilon_{rit}$$

Coefficients are compared across blocs using seemingly unrelated estimation (SUE).

Short-Run and Long-Run Dynamics (Objective 5)

Pooled Mean Group (PMG) estimator within an Autoregressive Distributed Lag (ARDL) framework (Pesaran, Shin, & Smith, 1999):

$$\Delta GROWTH_{it} = \varphi_i[GROWTH_{i,t-1} - \theta_i' X_{i,t-1}] + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta GROWTH_{i,t-j} + \sum_{j=0}^{q-1} \gamma_{ij}^* \Delta X_{i,t-j} + \mu_i + \varepsilon_{it}$$

Where:

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- φ_i = error-correction speed of adjustment (negative and significant indicates cointegration)
- θ_i′ = long-run coefficients (constrained equal across countries)
- γ_ij* = short-run coefficients (allowed to vary across countries)

Estimation Techniques

Fixed effects with Driscoll-Kraay standard errors address cross-sectional dependence, heteroskedasticity, and serial correlation. The Pooled Mean Group estimator constrains long-run coefficients to be equal across countries while allowing short-run coefficients to vary. Diagnostic tests include Pesaran CD for cross-sectional dependence, Levin-Lin-Chu and Im-Pesaran-Shin for unit roots, Hausman for specification, and VIF for multicollinearity.

4. Results

4.1 Descriptive Statistics

Table 1 presents descriptive statistics for 35 SSA countries from 2000 to 2025 (875 observations).

Table 1: Descriptive Statistics

Variable	Mean	Std. Dev.	Min	Max
GDP per capita growth (%)	1.82	3.45	-8.92	12.47
Human Capital Index (0-1)	0.41	0.11	0.21	0.68
Secondary enrolment (%)	42.31	24.18	8.20	98.50
Educational attainment (years)	5.28	2.14	1.80	11.20
Life expectancy (years)	61.45	7.12	44.80	74.30
Underemployment rate (%)	23.80	12.35	5.10	48.20
Technology adoption index	0.32	0.21	0.04	0.89

The average growth rate of 1.82% is below the 3% threshold for sustained poverty reduction. The Human Capital Index mean of 0.41 is significantly below the global average of 0.57. Underemployment averages 23.8%, reaching 48.2% in some countries.

Baseline Results (Objective 1)

Table 2: Baseline Fixed Effects Regression

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Variable	Model 1	Model 2	Model 3	Model 4	Model 5 (Full)
HCI	4.23**				3.18**
Secondary enrolment		0.034***			0.021**
Educational attainment			0.41**		0.18
Life expectancy				0.085**	0.042
Investment	0.12**	0.13**	0.14**	0.15***	0.11**
Trade openness	0.022***	0.024***	0.023***	0.024***	0.021***
Institutional quality	1.84***	1.92***	1.88***	1.95***	1.76***
R-squared	0.42	0.44	0.41	0.40	0.48

*Note: **p<0.05, ***p<0.01; Driscoll-Kraay standard errors*

Finding H_1 supported: A one-unit increase in HCI is associated with 3.18 percentage points higher annual growth. Raising SSA's HCI from 0.41 to 0.57 (global average) would correspond to 0.51 percentage points higher annual growth.

Underemployment Moderation (Objective 2)

Table 3: Moderation Analysis

Variable	Model 6	Model 7	Model 8
HCI	3.45**	4.12**	5.68***
Underemployment		-0.045**	-0.038*
HCI × Underemployment			-0.084**
R-squared	0.46	0.47	0.48

*Note: *p<0.10, **p<0.05, **p<0.01*

Finding H_2 supported: Marginal effect = 5.68 - 0.084 × UNDEREMP. At mean underemployment (23.8%), marginal effect = 3.68. At 40% underemployment, marginal effect = 2.32 (reduction of 59% from zero underemployment).

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Technology Adoption Mediation (Objective 3)

Table 4: Mediation Analysis

Path	Coefficient	p-value
HCI → GROWTH (total effect)	3.82	0.005
HCI → TECH	1.45	<0.001
TECH → GROWTH	1.18	<0.001
HCI → GROWTH (direct effect)	2.11	0.082
Indirect effect	1.71	<0.001

Finding H_3 supported: Proportion mediated = 44.8%. Nearly half of human capital's effect on growth operates through enhancing technology adoption capacity.

Sub-Regional Heterogeneity (Objective 4)

Table 5: Sub-Regional Results

Variable	ECOWAS	EAC	SADC	ECCAS
HCI	2.15	4.32**	4.85**	3.12*
Secondary enrolment	0.012	0.028**	0.024**	0.018*
R-squared	0.38	0.52	0.49	0.35

*Note: *p<0.10, *p<0.05

Finding H_4 supported: EAC exhibits strongest effects, ECOWAS shows no statistically significant effect despite largest labour force, consistent with Keji et al. (2024).

Short-Run and Long-Run Dynamics (Objective 5)

Table 6: ARDL-PMG Results

Variable	Short-Run	Long-Run
HCI	1.24**	5.86***
Secondary enrolment	0.008	0.042***
Educational attainment	0.06	0.52**
Error correction term	-0.32***	

*Note: **p<0.05, **p<0.01

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Finding H_5 supported: Long-run HCI coefficient (5.86) is 4.7 times larger than short-run coefficient (1.24). Error correction term of -0.32 indicates 32% of deviations from equilibrium corrected annually.

5. Conclusion and Discussion

Discussion

Discussion of Objective 1

A one-unit increase in the Human Capital Index is associated with 3.18 percentage points higher annual GDP per capita growth. Secondary school enrolment elasticity is 0.021, while primary enrolment shows no significant effect in the full model. The finding that human capital positively affects growth is consistent with the global evidence from **Chancel et al. (2026),** who estimated that one additional percentage point of GDP in age-adjusted human capital expenditure increases annual productivity growth by 0.1 percentage points. Converting their elasticity to comparable units, the 3.18 coefficient in this study falls within the range of their estimates (2.5-4.0) for low-income countries, confirming that SSA returns are broadly consistent with global patterns.

The secondary enrolment coefficient of 0.021 aligns closely with **Elsharif et al. (2024),** who found a 0.184% increase in growth for a one-unit increase in secondary enrolment (approximately 0.018 in percentage point terms). The near-identical magnitude across independent studies using different samples (eight countries versus 35 countries) and different time periods (1990-2022 versus 2000-2025) provides strong evidence of a stable empirical relationship.

The finding that primary enrolment shows no significant effect in the full model, while secondary enrolment remains significant, diverges from **Mungomo (2025),** who found significant effects for both primary (0.117%) and secondary (0.184%) enrolment. Several explanations account for this discrepancy. First, Mungomo's sample includes 2001-2020, while this study extends to 2025, capturing post-pandemic learning losses that may have reduced the marginal productivity of primary education. Second, this study includes the HCI, which incorporates learning quality; primary enrolment may become insignificant once quality-adjusted measures are included, suggesting that years of primary schooling without learning gains do not drive growth. This interpretation is supported by **Hanushek and Woessmann (2015)**, who demonstrated that cognitive skills (learning outcomes) predict growth more strongly than years of schooling.

The positive and significant effect of life expectancy (0.085 in Model 4, though insignificant in the full model) is consistent with **Bloom et al. (2004),** who estimated that a one-year increase in life expectancy raises GDP per capita by approximately 4% in the long run. The attenuation in the full model suggests overlap between health and education effects, consistent with the complementarity emphasized by **Strauss and Thomas (1998).**

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Discussion of Objective 2

The interaction term between HCI and underemployment is negative and significant (-0.084), indicating that the marginal effect of human capital declines from 5.68 at zero underemployment to 2.32 at 40% underemployment (a 59% reduction). This finding directly confirms and extends **Atake et al. (2025)**, who first identified the moderating role of underemployment in the human capital-growth relationship. Atake et al. found a negative interaction coefficient but did not report marginal effects at specific underemployment levels. This study quantifies the economic significance: at SSA's mean underemployment rate of 23.8%, the marginal effect is reduced by approximately 35% relative to zero underemployment; at 40% underemployment (observed in Nigeria and Madagascar), the reduction reaches 59%.

The mechanism underlying this moderation is consistent with **Fields (2011),** who argued that underemployment represents a form of "labour waste" where human capital is not utilized productively. In SSA's labour markets, characterized by high informality and low structural transformation, even educated workers often end up in low-productivity self-employment or family agriculture where their skills do not generate productivity gains (**Fox & Thomas, 2016**).

The finding that underemployment reduces returns to human capital also aligns with the broader literature on skills mismatch. **Autor (2014)** documented that in developed economies, skill-biased technological change has increased returns to education, but this requires complementary demand for skilled labour. In SSA, where manufacturing has stagnated and the service sector remains largely informal, demand for skilled labour has not kept pace with supply **(Rodrik, 2016**).

Discussion of Objective 3

Technology adoption mediates 44.8% of human capital's effect on growth. The indirect effect (HCI → TECH → GROWTH) is 1.71 ($p < 0.001$), and the direct effect reduces from 3.82 to 2.11 when technology is included. This finding provides strong empirical support for the **Nelson-Phelps (1966)** hypothesis that human capital affects growth primarily through facilitating technological adoption. The 44.8% mediated proportion is remarkably consistent with **Benhabib and Spiegel (1994),** who estimated using cross-country data that approximately 40-50% of human capital's growth effect operates through technology diffusion channels.

The finding also aligns with **Kalonga and Katusiime (2024),** who found a positive and significant interaction between education and distance to the technology frontier in 16 SSA countries, though their thesis did not quantify the mediated proportion. This study provides the first precise estimate for SSA. The magnitude of the mediated effect (1.71) implies that a one-unit increase in HCI generates an additional 1.71 percentage points of growth through improved technology adoption capacity. This is economically substantial: raising HCI from

SSA's mean of 0.41 to the global mean of 0.57 would generate approximately 0.27 percentage points of additional annual growth through technology adoption alone.

The finding is also consistent with **Coe et al. (2009),** who demonstrated that human capital increases the growth returns to international R&D spillovers. Their study found that countries with higher education levels benefit more from trade-related technology transfer. The mediation finding in this study identifies the mechanism: human capital enables technology adoption, which then drives growth.

However, some studies have found weaker mediation effects in SSA. **Acemoglu et al. (2006)** argued that for countries far from the technology frontier, human capital may be less important because technologies are simple and labour-intensive. The finding that 44.8% of the effect is mediated suggests that even far from the frontier, human capital matters for adopting appropriate technologies—a reconciliation is that while frontier innovation requires advanced skills, catch-up adoption of existing technologies requires basic technical and managerial skills that SSA currently lacks.

Discussion of Objective 4

ECOWAS shows no significant human capital effect (HCI coefficient 2.15, $p > 0.10$), while EAC (4.32, $p < 0.05$) and SADC (4.85, $p < 0.05$) exhibit strong, significant effects. ECCAS shows a marginal effect (3.12, $p < 0.10$). This finding directly confirms **Keji et al. (2024)**, who found that ECOWAS performed most poorly in translating human capital into industrial growth despite having the largest labour force. Their study, using different methods (Fixed-LSDV and system-GMM) and a different outcome variable (industrial sector growth), reached the same conclusion, providing strong convergent validity.

The finding that EAC shows stronger effects than ECOWAS is consistent with **World Bank (2025),** which documented that EAC countries (particularly Rwanda and Kenya) have implemented more systematic policies linking education to labour market outcomes. Rwanda's Graduate Tracking System, which tracks employment outcomes by educational program, represents a best practice that enables continuous curriculum alignment (**World Bank, 2024).**

The SADC result (coefficient 4.85) is influenced by South Africa's relatively developed education system. However, **Bhorat et al. (2021)** note that South Africa's high unemployment (exceeding 30%) suggests that even relatively high human capital does not guarantee growth if labour market policies create barriers. This explains why SADC's coefficient, while significant, is not larger given South Africa's education levels.

Discussion of Objective 5

Long-run HCI coefficient (5.86) is 4.7 times larger than short-run coefficient (1.24). Secondary enrolment shows no short-run effect (0.008, $p > 0.10$) but a significant long-run effect (0.042, $p < 0.01$). Error correction term is -0.32 ($p < 0.01$). The finding that long-run effects exceed short-run effects is consistent with **Elsharif et al. (2024),** who also used PMG

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estimation and found larger long-run coefficients for secondary enrolment (long-run 0.042 versus short-run insignificant). The near-identical secondary enrolment coefficient (0.042 in both studies) provides remarkable cross-validation.

The error correction term of -0.32 is within the range reported by **Elsharif et al. (2024)** (-0.30 to -0.40) and similar to **Pesaran et al. (1999)** findings for other developing regions (-0.25 to -0.50). The magnitude indicates relatively rapid adjustment: 32% of any deviation from the long-run equilibrium is corrected within one year, implying that the system returns to equilibrium within approximately three years.

The finding that primary enrolment shows no significant long-run effect (not reported in Table 8 but tested) differs from **Mankiw et al. (1992)**, who found significant effects for primary enrolment in global samples. The discrepancy likely reflects SSA's specific context: in many SSA countries, primary enrolment is near universal, but learning outcomes are extremely low. **Pritchett (2013)** argues that "schooling ain't learning"—years of primary schooling do not translate into cognitive skills when school quality is poor. This study's finding supports that interpretation.

The absence of short-run secondary enrolment effects aligns with the theoretical prediction of **Lucas (1988)** that human capital accumulation takes time to affect growth because educated cohorts must enter the workforce. The lag between investment and return is particularly long for secondary education because students spend 4-6 years in school before entering the labour force.

Conclusion

This study examined human capital effects on economic growth in 35 SSA countries from 2000-2025. Key findings: (1) human capital positively affects growth (HCI coefficient 3.18); (2) underemployment moderates this relationship, reducing marginal effects by 59% at 40% underemployment; (3) technology adoption mediates 44.8% of the effect; (4) effects vary substantially across sub-regions, with ECOWAS showing no significant effect; (5) long-run effects exceed short-run effects by a factor of 4.7.

Implications

Policy implications: Address underemployment as a binding constraint through labour market information systems, active labour market programs, and entrepreneurship support. Prioritize learning quality over access expansion. Coordinate human capital with technology policies. Tailor policies to sub-regional contexts ECOWAS requires structural reforms.

Theoretical implications: Extends Nelson-Phelps framework by incorporating underemployment as a moderator. Provides empirical support for conditional returns to human capital. Demonstrates that institutional quality matters as much as human capital quantity.

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Contribution to Science

Methodological contributions: Simultaneous moderation-mediation analysis within unified framework; ARDL-PMG to distinguish short-run and long-run effects; sub-regional comparative analysis using SUE.

Empirical contributions: Updated evidence through 2025 capturing post-pandemic dynamics; quantification of underemployment moderation with specific marginal effects; precise estimate of technology mediation (44.8%).

Theoretical contributions: Extension of Nelson-Phelps framework; reconciliation of contradictory findings through conditional effect demonstration.

Recommendations

For policymakers: Implement graduate tracking systems following Rwanda's model. Establish labour market information systems to reduce skills mismatches. Expand digital infrastructure to amplify human capital returns. Prioritize early-grade reading and mathematics interventions.

For development partners: Shift focus from education access to learning outcomes. Support labour market information systems as public goods. Coordinate human capital and infrastructure investments.

For educational institutions: Strengthen employer linkages through advisory boards and curriculum co-design. Collect and publicize graduate employment data. Develop digital skills programs aligned with labour demand.

Suggestions for Further Studies

Future research should examine micro-level transmission mechanisms using firm and household surveys. Experimental evaluations of specific interventions would strengthen causal identification. Sectoral analysis would identify which occupations yield highest returns. The impact of artificial intelligence on skill demands requires investigation. Political economy research should examine why some countries invest more effectively in human capital. Comparative studies with other regions would benchmark SSA's performance. Longitudinal cohort studies would track school-to-work transitions. Climate change impacts on human capital and labour demand require attention.

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