East African Journal of Business and Economics
eajbe.eanso.org
Volume 8, Issue 1, 2025
Print ISSN: 2707-4250 | Online ISSN: 2707-4269
Title DOI: https://doi.org/10.37284/2707-4269

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania

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Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

Date Published:

22 May 2025

Keywords:

Economic Growth, Gross Capital Formation, Population Growth, Technological Progress, Solow-Swan growth model, VECM, Tanzania.

ABSTRACT

The drivers of economic growth in developing countries remain a subject of ongoing debate. While rapid population growth is sometimes seen as expanding the labour force and market size, it is also argued to strain resources and infrastructure. Meanwhile, capital accumulation and technological progress are widely recognised as key to sustainable growth. This study examines these dynamics in Tanzania using the Solow-Swan growth model and annual data from 1974 to 2023. Applying Johansen cointegration, Vector Error Correction Model (VECM), and Granger causality tests, the findings reveal that population growth negatively impacts economic growth (GDP) in the long run (-5.589, $p < 0.01$). In contrast, gross capital formation (1.092, $p < 0.01$) and technological progress (5.711, $p < 0.01$) significantly promote economic growth. The error correction term (–0.514, $p < 0.01$) indicates GDP adjusts toward long-run equilibrium at a speed of 51.4% annually. Granger causality tests reveal bidirectional causality between GDP and population growth, and unidirectional causality from capital formation and population growth to GDP. Although technological progress has a negative short-term effect ($p < 0.1$), its long-term impact is strongly positive ($p<0.01$), indicating transitional adjustments. The study confirms the relevance of the Solow-Swan model for Tanzania and underscores the importance of capital investment, technological innovation, and demographic management. These findings provide policy insights to foster sustainable growth by promoting productive investment, advancing technology, and managing population growth effectively in Tanzania and similar developing economies.

APA CITATION

Mbwambo, S. K., Setonga, J. A. & Laurent, M. F. (2025). Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania. *East African Journal of Business and Economics*, *8*(1), 443-458. https://doi.org/10.37284/eajbe.8.1.3030.

CHICAGO CITATION

Mbwambo, Seth Kenedi, Jumanne A. Setonga and Mpfubhusa F. Laurent "Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania". *East African Journal of Business and Economics* 8 (1), 443-458. https://doi.org/10.37284/eajbe.8.1.3030.

HARVARD CITATION

Mbwambo, S. K., Setonga, J. A. & Laurent, M. F. (2025) "Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania", *East African Journal of Business and Economics*, 8(1), pp. 443-458. doi: 10.37284/eajbe.8.1.3030.

IEEE CITATION

S. K., Mbwambo, J. A., Setonga & M. F., Laurent "Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania", *EAJBE*, vol. 8, no. 1, pp. 443-458, May. 2025.

MLA CITATION

Mbwambo, Seth Kenedi, Jumanne A. Setonga & Mpfubhusa F. Laurent "Unveiling the Interlinkages Among Population Growth, Gross Capital Formation, Technological Progress, and Economic Growth in Tanzania". *East African Journal of Business and Economics*, Vol. 8, no. 1, May. 2025, pp. 443-458, doi:10.37284/eajbe.8.1.3030.

INTRODUCTION

Tanzania's economic growth has been significantly influenced by demographic changes, capital investments, and technological advancements (Kahyarara, 2019). Over the past decade, the country's population has grown from approximately 44.9 million in 2012 to 61.7 million in 2022, reflecting an average annual growth rate of 3.2% (National Bureau of Statistics (NBS), 2022). Projections indicate that this trend will continue, with the population expected to reach 123.5 million by 2044 (NBS, 2022). Population growth can catalyse economic expansion by increasing the labour force and consumer market. However, rapid population growth also presents challenges, including pressure on resources, infrastructure, and employment opportunities, which can ultimately hinder economic progress without sufficient capital investment and technological advancements (Mahtta *et al*., 2022; Kahyarara, 2019; Mpfubhusa & Devotha, 2024).

In Tanzania, infrastructure spending comprises approximately 41% of total capital expenditure, with a focus on transport, communication, and construction (Kanval *et al*., 2024; Achar *et al*., 2024). Despite these investments, concerns persist regarding the efficiency of public infrastructure in stimulating private-sector growth and productivity. Meanwhile, technological progress, driven by digitalisation and innovation, is another critical factor shaping economic growth. Tanzania's urban population has risen sharply, from 8.4 million in 2002 to 22.8 million in 2021, facilitating greater access to the labour force and modern services (World Bank, 2024). However, while population growth has the potential to drive productivity and efficiency, its impact on economic growth in Tanzania remains underexplored.

Existing research has extensively examined the individual impacts of population growth, capital formation, and technological progress on economic growth, yet there remains a lack of integrated analysis that considers the interplay between these factors. Most studies focus on population growth as a determinant of economic performance (Mose, 2021; Mahtta *et al*., 2022). Other studies on the role of capital investment in infrastructure and the private sectors on economic development (Kanval *et al*., 2024; Sun *et al*., 2023; Achar *et al*., 2024; Shabbir *et al*., 2021). All these studies present inconclusive results. However, there is limited empirical evidence on how these three elements interact to shape long-term economic growth in Tanzania. Additionally, while studies recognise the importance of technological progress, few have quantified its contribution to productivity as proposed by Solow-Swan theory (Hinneh, 2025; Ding *et al*., 2021; Mohsin *et al*., 2022). Furthermore, previous studies have not sufficiently addressed the causality between these factors and economic growth, relying primarily on correlation-

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

based analyses rather than robust econometric approaches that can establish causal relationships (Hinneh, 2025; Mose *et al*., 2024; Ding *et al*., 2021)

Addressing these gaps is essential for formulating effective policies that promote sustainable economic growth. A study that integrates population dynamics, gross capital formation, and technological progress offers a more comprehensive understanding of the fundamental drivers of economic performance. By utilising recent data and employing advanced econometric techniques such as Vector Error Correction Models (VECM) and Granger causality tests, this study aims;

- To examine the effect of population growth, capital formation, and technological progress on economic growth.
- To determine the causal relationship between population, capital formation, technological progress, and economic growth.
- To ascertain if the Solow-Swan growth theory applies in Tanzania-type economies.

The structure of the paper is as follows: Section 2 presents a comprehensive literature review, encompassing both theoretical foundations and empirical evidence relevant to the study. Section 3 outlines the materials and methods, detailing the econometric models employed and the data sources utilised. Section 4 reports the empirical results, while Section 5 offers an in-depth discussion of the findings. Finally, Section 6 concludes the study by summarising the key insights and outlining the policy implications derived from the analysis.

LITERATURE REVIEW

Theoretical Underpinnings

Solow-Swan Growth Theory

The Solow-Swan Growth theory, developed independently by Robert Solow and Trevor Swan in 1956, remains one of the most influential economic growth theories. The model argues that long-term economic growth is primarily driven by capital accumulation, labour force expansion, and technological progress (Kawalec, 2020). It assumes a neoclassical production function with constant returns to scale and diminishing marginal returns to capital and labour. A key insight of the model is that without technological progress, economies will eventually reach a steady state where additional investments in capital no longer lead to sustained growth (Daly, 2014). Technological progress, treated as an exogenous factor, is considered the ultimate driver of long-term per capita income growth, making it critical to understand how economies develop over time (Solow, 1956).

Despite its simplicity, the model provides a robust framework for analysing the contributions of population growth, capital formation, and technological progress to economic expansion (Missaglia & Vaggi, 2025). By applying the Solow-Swan model, this research will assess how these factors influence Tanzania's economic growth trajectory. Although the model has been widely adopted in growth studies, it has several limitations. One major criticism is its assumption that technological progress is exogenous, meaning that advancements in technology occur independently of economic policies, institutional changes, or innovation-driven investments. Additionally, the model does not explicitly incorporate human capital, institutions, or other structural factors that influence economic development (Mankiw *et al*., 1992). The Solow-Swan model remains a dominant framework for analysing Tanzania's economic growth due to its clear and testable predictions regarding capital, labour, and output. Its strength lies in providing a structured and quantifiable approach to assessing key growth determinants. While endogenous growth theories emphasise innovation, the Solow-Swan model remains relevant for capturing capital formation, population growth, and technology. Its empirical robustness is evident in recent studies that apply it to developing economies. This confirms its continued relevance in

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

understanding economic expansion (Kumar & Kober, 2012; Sunde, 2017; Tang & Rosidi, 2025).

Empirical Review

Empirical studies on the relationship between population growth, capital formation, and technological progress offer mixed views on how these factors drive economic growth. Galor, & Moav (2015) argue that technological innovation can mitigate the negative impacts of population growth by boosting per capita output, suggesting a compensatory effect of innovation. Supporting this view, Ntamwiza, & Masengesho (2022) find that both Gross Capital Formation (GCF) and Foreign Direct Investment (FDI) significantly contribute to Rwanda's economic growth, with FDI notably enhancing capital accumulation and enabling technology transfer. Similarly, Nweke *et al.* (2017) emphasise GCF's crucial role in Nigeria, particularly in strengthening infrastructure and developing human capital.

Conversely, other researchers emphasise the potentially adverse effects of population growth when not matched by adequate investments in human capital and technology. Bucci *et al*. (2018), Mose (2021), and Mahtta *et al*. (2022) highlight the “dilution effect,” where rapid population growth strains limited capital and natural resources, reducing per capita income. However, scholars like Wu (2024) and Kumar (2012) provide a more optimistic view, suggesting that population growth and technological advancement can be complementary, with innovation fostering better education systems and a productive workforce. Huang (2016) adds that long-run growth can be stimulated by population increases if accompanied by human capital investment, as it improves labour productivity and spurs innovation. Heintz and Folbre (2022) explore the broader demographic dynamics, noting how ageing populations interact with technology to shape economic structures. Jafrin et al. (2021) focus on the demographic dividend in emerging economies, showing that a youthful population can boost growth if supported by investments in education and skills. Bucc and Raurich (2015) reinforce that population growth, when paired with human capital and technology, can drive sustained development. Finally, Li (2024) and Agbeyangi *et al*. (2024), using the Solow-Swan growth model in Russia and Kenya, respectively, conclude that technological progress is the principal engine of long-term growth, with capital and labour playing secondary roles due to diminishing returns.

Despite growing literature on the individual effects of population growth, capital accumulation, and technological progress on economic progress, most studies adopt isolated or fragmented approaches, particularly within developing country contexts. In Tanzania, limited empirical work has explored these variables jointly within an integrated analytical framework. Moreover, the applicability of the Solow-Swan growth model remains empirically untested in the Tanzanian setting, where structural rigidities and institutional constraints may influence long-run growth dynamics. This gap underscores the need for a comprehensive analysis that examines the interdependencies among these growth drivers and evaluates the model’s relevance in shaping context-specific development policies.

Conceptual Framework

The conceptual framework illustrates the dynamic interlinkages between population growth, gross capital formation, technological progress, and economic growth. Population growth contributes to an expanding labour force, which, when complemented by increased investment in physical capital (gross capital formation), enhances the economy’s productive capacity. Technological progress plays a critical role by improving the efficiency of both labour and capital, thereby boosting total factor productivity. Together, these factors interact to drive sustained economic growth.

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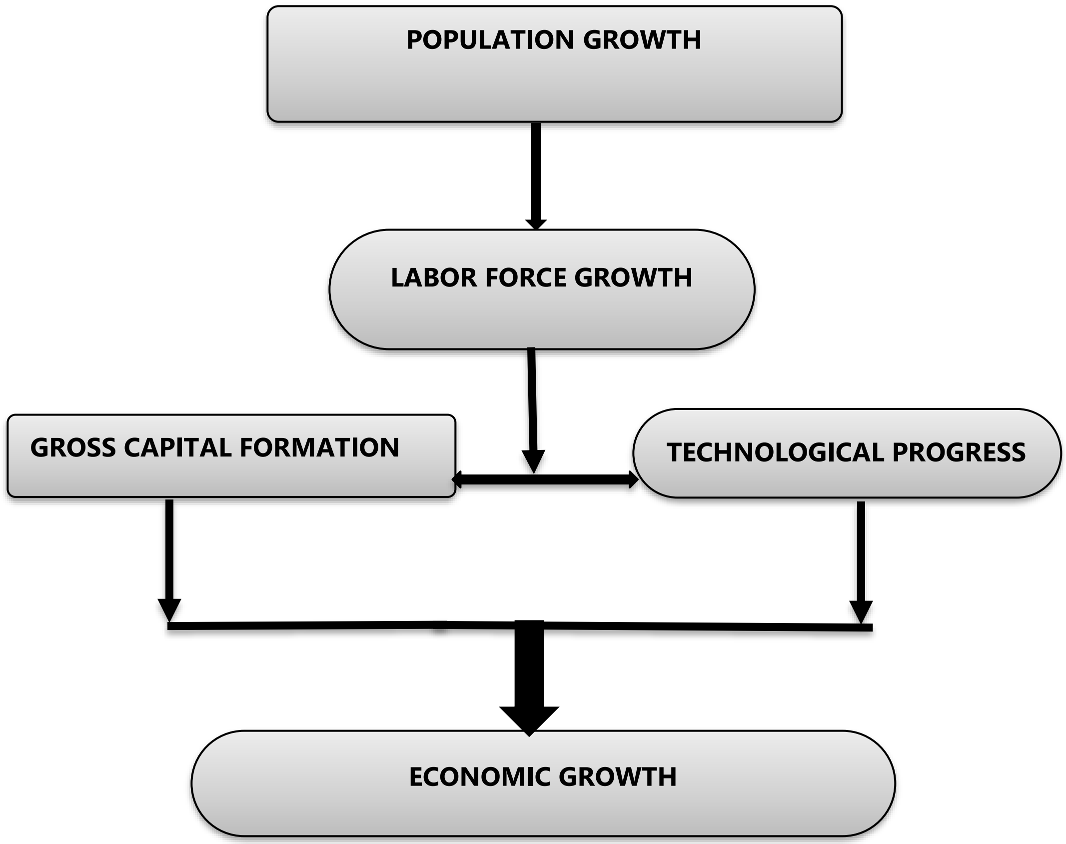
Figure 1: Conceptual Framework



Source: *Author's design*

Hypotheses

H_{01}: Population growth, capital formation, and technological progress have no significant effect on economic growth in Tanzania.

H_{02}: There is no causal relationship between population growth, capital formation, technological progress, and economic growth in Tanzania.

H_{03}: The Solow-Swan growth theory does not apply to Tanzania-type economies.

MATERIALS AND METHODS

Data Sources

This study utilises time series data spanning 1974 to 2023, obtained from credible international and national databases. Specifically, the data on Gross Domestic Product (GDP), Gross Capital Formation (GCF), and Population Growth were sourced from the World Bank (WB) and the National Bureau of Statistics (NBS) of Tanzania. Data on technological progress proxied by Total Factor Productivity (TFP) were extracted from the Penn World Table (PWT).

Econometric Modelling

Data analysis in this study was conducted using STATA software, employing a combination of advanced econometric techniques to ensure robust and reliable results. Before estimation, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests were applied to test for stationarity in the time series data, as non-stationary variables can lead to spurious regression results. If variables were found to be integrated of order one, Johansen's Co-integration Test was conducted to determine the existence of long-run equilibrium relationships

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among them (Mbwambo & Mchukwa, 2024; Daudi & Setonga, 2024).

To analyse the short-run dynamics, the Vector Error Correction Model (VECM) was employed, allowing for adjustments toward equilibrium in a co-integrated series. Additionally, Granger Causality tests were used to examine the direction of causality between the variables, determining whether past values of one variable could statistically predict another (Mbwambo & Mchukwa, 2024). The Granger causality equation was specified as:

$$Y_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i Y_{t-i} + \sum_{j=1}^{n} \beta_j Y_{t-j} + \varepsilon_t \quad (1)$$

Where the null hypothesis H_0: X does not Granger cause Y. Rejection of H_0: implies a causal relationship.

The Solow-Swan growth model underpins the study, which explains output as a function of capital, labour (population), and technology. The basic Cobb-Douglas production function is specified as:

$$Y_t = A_t K_t^{\alpha} L_t^{1-\alpha} \quad (2)$$

Where:

Y_t = Output (GDP) at time *t*; A_t= Level of technology (TFP); K_t= Capital input

K_t= Labor input (proxied by population); α= Output elasticity of capital (0 < α < 1)

To make them linear, apply the natural logarithms on both sides; it follows;

$$lnY_t = lnA_t + \alpha lnK_t + (1-\alpha) ln\, L_t \quad (3)$$

In empirical growth analysis, especially for time series estimation, technology. A_t is unobserved, so it is proxied using Total Factor Productivity (TFP) and Gross Capital Formation (GCF) as a proxy for K_t.

$$lnY_t = \beta_0 + \beta_1 lnGCFt + \beta_2 lnPOPt + \beta_3 lnTFPt + \varepsilon_t \quad (4)$$

Where:

$lnY_t =$ Log of GDP; $lnGCFt$= Log of Gross Capital Formation; $lnPOPt$= Log of Population; $lnTFPt$= Log of technological progress; ε_t= Error term

Vector of Endogenous Variables

Assume all variables are non-stationary I(1) and are cointegrated, meaning they share a long-run equilibrium relationship. Then the vector of endogenous variables is given as;

$$X_t = \begin{bmatrix} lnY_t \\ lnGCF_t \\ lnPOP_t \\ lnTFP_t \end{bmatrix} \quad (5)$$

The general VAR (p) model:

$$X_t = A_1 X_{t-1} + A_2 X_{t-2} + \cdots \ldots \ldots \ldots \ldots + A_P X_{t-P} + \varepsilon_t \quad (6)$$

If the variables are cointegrated, we must difference the variables and introduce an error correction term. The VECM is derived by rewriting VAR (p) in its error correction form:

Vector Error Correction Model (VECM)

Given evidence of co-integration, the VECM is estimated to capture both the short-term dynamics and long-run relationships. The general VECM specification is:

$$\Delta X_t = \Pi X_{t-1} + \sum_{i=1}^{k-1} \Gamma_i \Delta X_{t-i} + \mu + \varepsilon_t \quad (7)$$

X_t= Vector of endogenous variables; Π= Co-integration matrix; Γ_i= Short-run adjustment coefficients. μ= Constant, ε_t= Error term. The error correction term (ECT) derived from the co-integrating equation reflects the speed at which the system adjusts back to equilibrium after a short-run shock.

$$\Delta lnY_t = \gamma_0 + \lambda_1 ECT_{t-1} + \sum_{i=1}^{k-1} \gamma_{1i} \Delta \ln Y_{t-i} + \sum_{i=1}^{k-1} \gamma_{2i} \Delta \ln GCF_{t-i} + \sum_{i=1}^{k-1} \gamma_{3i} \Delta \ln POP_{t-i} + \sum_{i=1}^{k-1} \gamma_{4i} \Delta \ln TFP_{t-i} + \varepsilon_t \quad (8)$$

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$$ECT_{t-1} = \Delta lnY_t - \beta_1 lnGCF_{t-i} - \beta_2 lnPOP_{t-i} - \beta_3 lnTFP_{t-i} \quad (9)$$

ECT_{t-1}= the error correction term

λ_1= the speed of adjustment back to equilibrium

γ_{ij} = Short-run coefficients

ε_t = White noise error term

RESULTS

Table 1a: Description and Measurement of the Variable

Variables	Measurement/Proxy	Source of Data
Economic Growth (GDP)	Real GDP (constant US$)	World Bank (WB)
Population Growth (POP)	Annual Population Growth Rate (%)	National Bureau of Statistics (NBS)
Gross Capital Formation (GCF)	Gross Capital Formation as % of GDP	World Bank (WB)
Technological Progress (TFP)	Total Factor Productivity (TFP)	Penn World Tables (PWT)

Source: *Authors from WB, NBS, & PWT (2025)*

Table 1a provides an overview of the variables used in the study, detailing their measurement and data sources. The key dependent variable in this study is Gross Domestic Product (GDP), measured as GDP per capita in current US dollars, with data sourced from the World Bank (2024). The independent variables include Population (POP), which is measured as the total population and sourced from the National Bureau of Statistics (NBS, 2024). Another independent variable, Gross Capital Formation (GCF), is measured in current US dollars and sourced from the World Bank (2024). The final variable, Technological progress (TFP), is calculated as the ratio of output over factor inputs (labour and capital), with data obtained from PWT (2024)

Table 1b: Descriptive Statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
lnGDP	50	6.274	0.5	5.414	7.11
lnPOP	50	17.304	0.419	16.56	18.014
lnGCF	50	20.674	2.416	17.536	24.057
lnTFP	50	5.183	0.103	4.984	5.305

Source: *Authors' Computation (2025)*

Table 1b presents the descriptive statistics for the variables. The GDP variable (lnGDP) has a mean of 6.274 and a standard deviation of 0.5, suggesting moderate variability in GDP across the dataset. The Population variable (lnPOP) has a mean of 17.304 with a standard deviation of 0.419, showing relatively lower variability in the total population over time. Gross capital formation (lnGCF) has a mean of 20.674 with a standard deviation of 2.416, suggesting that capital formation exhibits significant fluctuations across the study period. The wide range of values, from 17.536 to 24.057, supports this observation. Lastly, technological progress (lnTFP) has a mean of 5.183 with a low standard deviation of 0.103, indicating minimal variation over time.

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

Table 2: Unit Root Test

Augmented Dickey-Fuller Test			Phillip Perron Test		Ord
Variable	t-statistic	Critical value (1%)	t-statistic	Critical value (1%)	
lnGDP	-4.285***	-3.594	4.308***	-4.168	I(1)
lnPOP	-3.756***	-3.594	-3.753***	-4.168	I(1)
lnGCF	-7.774***	-3.594	-7.235***	-4.168	I(1)
lnTFP	-7.249***	-3.594	-7.714***	-4.168	I(1)

******* *p <0.01*

Source: *Authors' Computation (2025)*

Table 2 presents the results of the Augmented Dickey-Fuller (ADF) test and Phillips-Perron (PP) test for stationarity. The results indicate that all four variables, GDP, population, capital formation, and total factor productivity, are integrated of order one, I (1). This means that the variables are non-stationary at their levels but become stationary after first differencing. The ADF test t-statistics for GDP (-4.285), Population (-3.756), gross capital formation (-7.774), and total factor productivity (-7.249) are all lower than the critical value at the 1% level (-3.594), confirming that these variables become stationary after first differencing. Similarly, the Phillips-Perron test results are consistent with the ADF test, confirming that the variables follow an I (1) process.

Table 3: Lag Selection

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	-9.2932		2.1e-05	0.577965	0.637532	0.736977
1	320.515	659.62	2.5e-11	-13.0659	-12.768	-12.2708
2	353.916	66.802	1.2e-11	-13.8224	-13.2863	-12.3913
3	386.934	66.037	5.9e-12	-14.5623	-13.788	-12.4952*
4	410.446	47.025*	4.7e-12*	-14.889*	-13.8763*	-12.1858

*Note: * lag selected by the criteria*

Source: *Authors' Computation (2025)*

Table 3 reports the results of the lag length selection for the Vector Error Correction Model (VECM). Different criteria, including the Akaike Information Criterion (AIC), Hannan-Quinn Criterion (HQIC), and Schwarz Bayesian Information Criterion (SBIC), were used to determine the optimal lag length. Based on the results, the optimal lag length is 4, as indicated by the asterisks (*) under the various selection criteria. The Likelihood Ratio (LR) test also supports the selection of 4 lags. This means that four previous periods of data are used in the analysis to capture dynamic relationships between the variables.

Table 4: Johansen Test for Cointegration

Max rank	Params	LL	Eigenvalue	Trace statistic	Critical value 5%
r=0	52	382.00996		56.8729	47.21
r≤ 1	59	399.09423	0.52422	22.7043*	29.68
r≤ 2	64	407.89279	0.31788	5.1072	15.41
r≤ 3	67	410.40903	0.10363	0.0747	3.76
r≤ 4	68	410.44639	0.00162		

* Selected rank

Source: *Authors' Computation (2025)*

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

The Johansen cointegration test results in *Table 4* indicate the presence of a long-run equilibrium relationship among the variables. The trace statistic suggests that one cointegrating equation exists at the 5% significance level. Specifically, the test finds that at rank 1, the trace statistic (22.7043) is below the critical value (29.68), confirming that the system has at least one long-run equilibrium relationship. This result justifies using the Vector Error Correction Model (VECM), which accounts for both short-run dynamics and long-run relationships among the variables.

Table 5: Short-Run Vector Error Correction Model

	D.lnGDP	D.lnPOP	D.lnGCF
Error Correction term (ECT)	-0.514***	0.000	-0.596***
	(0.032)	(0.001)	(0.127)
Economic growth (lnGDP)	0.288***	-0.003	-0.411
	(0.162)	(0.003)	(0.638)
L2D	-0.15	0.006**	2.207***
	(0.167)	(0.003)	(0.656)
L3D	0.285	0.004	1.425*
	(0.194)	(0.003)	(0.762)
Population growth (lnPOP)	-14.692*	0.996***	-12.553
	(7.757)	(0.129)	(30.521)
L2D	6.054	-0.354**	62.436
	(10.055)	(0.167)	(39.562)
L3D	0.956	0.125	-50.281*
	(6.681)	(0.111)	(26.289)
Gross capital formation (GCF)	0.013	0.002***	0.12
	(0.036)	(0.001)	(0.14)
L2D	0.088**	-0.001**	0.011
	(0.037)	(0.001)	(0.147)
L3D	0.059	-0.003***	-0.044
	(0.038)	(0.001)	(0.148)
Technological progress (TFP)	-0.956*	0.001	-2.239
	(0.515)	(0.009)	(2.025)
L2D	1.8***	0.000	-0.03
	(0.689)	(0.011)	(2.71)
L3D	2.318**	-0.014	-8.237**
	(1.002)	(0.017)	(3.944)

****** $p<0.01$*, ** $p<0.05$, * $p<0.1$** *Standard errors in parentheses*

Source: *Authors' Computation (2025)*

The VECM estimates in *Table 5* show the short-run relationship between the variables. The error correction term (ECT) for GDP is (*-0.514, $p<0.05$*), which is negative and statistically significant. This indicates that GDP adjusts towards its long-run equilibrium at a rate of 51.4%. Population growth (lnPOP) has a significant negative impact on GDP in the short run (*-14.692, $p<0.1$*). This suggests that higher population growth may exert downward pressure on GDP. The gross capital formation (lnGCF) has a positive and significant effect on GDP at a two-period lag of (*0.088, $p<0.05$*), confirming that investment in capital drives economic growth in the short run. Technological progress (lnTFP) negatively impacts GDP in the short run (*-0.956, $p<0.1$*), but becomes positive at longer lags. Furthermore, for population growth (ΔlnPOP), the coefficient of lagged population (lnPOP) is (*0.996, $p<0.01$*), showing strong persistence over time. The gross capital formation

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

(lnGCF) has a positive short-run effect on population growth with a coefficient of (*0.002, p<0.01*). However, its later lags exhibit negative effects (*–0.001, p<0.05*) and (*–0.003, p<0.01*), suggesting a delayed reduction in population growth. For gross capital formation (ΔlnGCF), the error correction term (ECT) is significant (*–0.596, p<0.01*), confirming adjustment toward long-run equilibrium. Gross capital formation is positively influenced by GDP (*2.207, p<0.01*), while a later lag of TFP exerts a negative effect *(–8.237, p<0.05*), indicating a delayed adverse impact on investment.

Table 6: Model Summary

Equation	**Parms**	**RMSE**	R^2	**chi2** (χ^2)	**P>chi2**
D.lnGDP	14	0.092842	0.5697	42.3725	0.0001
D.lnPOP	14	0.001546	0.9981	16690.79	0.0000
D.lnGCF	14	0.365293	0.6083	49.69241	0.0000

Source*: Authors' Computation (2025)*

Table 6 provides summary statistics for the model fit. The R-squared values indicate the proportion of variation explained by the model: GDP (0.5697), Population (0.9981), and gross capital formation (0.6083). The chi-squared (χ^2) values for all equations are statistically significant (*p<0.01*), confirming that the model has strong explanatory power.

Table 7: Johansen Normalisation-Restriction

Variable	**Coefficient**	**Standard Errors**	**z**	**P>|z|**
GDP	1			
lnPOP	-5.58938***	1.410153	-3.96	0.0000
lnGCF	1.092806***	0.242907	4.5	0.0000
lnTFP	5.71121**	2.137653	2.67	0.008

**** p<0.01***, **** *p<0.05***, *** *p<0.1*

Source*: Authors' Computation (2025)*

Table 7 presents the long-run equilibrium relationships estimated using the Johansen cointegration method. The results indicate that population has a significant negative long-run effect on GDP *(–5.589, p* < 0.01), while gross capital formation positively influences GDP (*1.092, p < 0.01*). Similarly, technological progress (lnTFP) also has a positive and significant effect on GDP (*5.711, p < 0.01*).

Table 8: Diagnostic Test

Post Diagnostic Test		
Jarque-Bera: Normality test:	1.558	$Probability\ of\ Chi\ (2) = 0.4589$
LM test for Autocorrelation	20.7075	$Probability\ of\ Chi\ (2) = 0.1900$

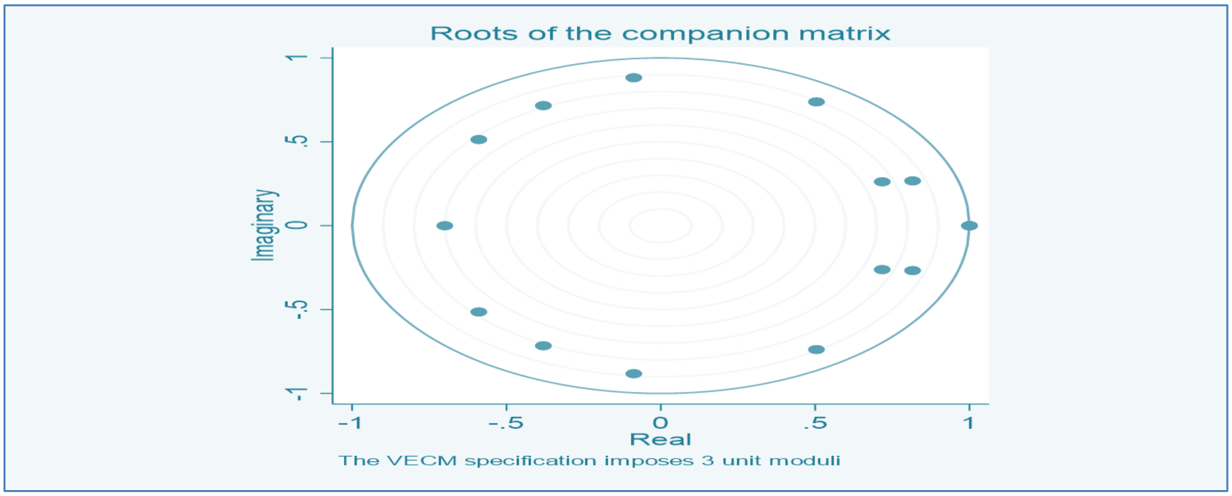
Source*: Authors' Computation (2025)*

The diagnostic tests in *Table 8* confirm that the model meets the necessary statistical assumptions. The Jarque-Bera test for normality (*p>0.05)* indicates that the residuals are normally distributed. The LM test for autocorrelation (*p>0.05*) suggests no significant autocorrelation in the residuals.

VECM Stability Test

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

Figure 2: Companion Matrix for VECM Stability



Source*: Authors' Computation (2025)*

The VECM Stability Test (*Figure 2*) further confirms that the estimated model is stable since all imaginary points fall within the unit moduli of the companion matrix. Thus, the model is stable toward short-term and long-run shocks.

Table 9: Granger Causality Test

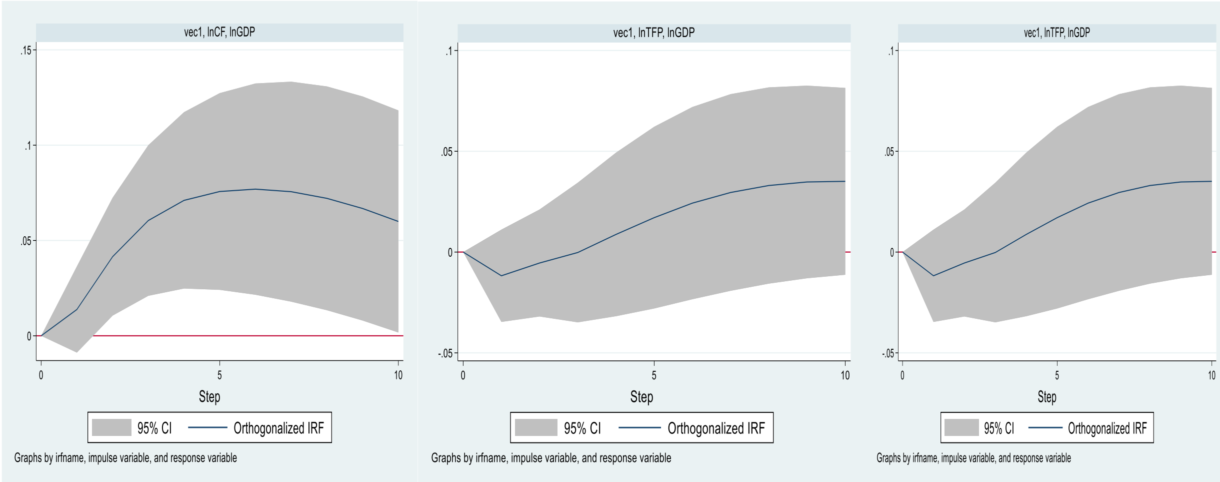
Equation	Excluded	chi2	df	Prob(chi2)	Direction
lnGDP	lnPOP	9.1561	2	0.010	lnPOP → lnGDP
lnGDP	lnGCF	9.8342	2	0.007	lnGCF → lnGDP
lnPOP	lnGDP	25.909	2	0.000	lnGDP → lnPOP
lnPOP	lnGCF	27.974	2	0.000	lnGCF → lnPOP
lnGCF	lnPOP	6.9913	2	0.030	lnPOP → lnGCF
lnTFP	lnGDP	6.2408	2	0.044	lnGDP → lnTFP

Source*: Authors' Computation (2025)*

The Granger causality results indicate a bidirectional relationship between GDP and Population, meaning that GDP growth influences population changes, and population growth, in turn, impacts GDP. Additionally, unidirectional causality is observed where population and capital formation both significantly drive GDP growth, while GDP influences total credit. Moreover, population impacts gross capital formation, and capital formation influences population. These findings highlight the interconnected roles of economic growth, demographic changes, and investment dynamics.

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

Figure 3: Impulse Response Function



Source*: Authors' Computation (2025)*

Figure 3 illustrates how GDP, population, gross capital formation, and productivity respond to external shocks over time. The results show that GDP responds positively to capital formation shocks, meaning investment boosts economic growth in the long run. In contrast, shocks to total factor productivity initially reduce GDP, indicating short-term inefficiencies before productivity gains materialise. The population growth has a persistent effect on GDP, but the direction depends on other economic factors.

Applicability of Solow-Swan Growth Theory in Tanzania-type Economies

The empirical findings from the VECM estimation strongly support the applicability of the Solow-Swan growth theory in Tanzania-type economies, where capital accumulation, labour (population), and productivity dynamics interact to shape long-run economic growth. The significant and negative error correction term (ECT) for GDP confirms the presence of a long-run equilibrium, with GDP adjusting towards its steady state at a rate of 51.4%, consistent with the theory's premise of convergence. The positive and significant lagged effects of capital formation on GDP validate the Solow model's emphasis on investment as a key driver of short-run growth, while the negative short-run impact of population growth aligns with the theory's assertion that excessive labour increases, without corresponding capital deepening, may dilute output per worker. Moreover, the mixed effects of technological progress (TFP) are negative in the short run but positive at later lags, suggesting transitional dynamics where productivity gains materialise over time, reflecting the delayed benefits of technological advancement as highlighted in the Solow framework.

DISCUSSION

The study examined the impact of population growth, capital formation, and technological progress on economic growth in Tanzania, assessed their causal relationships, and evaluated the applicability of the Solow-Swan growth model. The findings indicate that gross capital formation and technological progress positively affect economic growth, while population growth hurts GDP. The Vector Error Correction Model (VECM) shows that GDP adjusts toward its long-run equilibrium at a rate of 51.4% after a shock. In the short run, capital formation significantly contributes to economic growth (*0.088, p=0.019*), reinforcing Achar *et al*. (2024), who found that gross fixed capital formation drives economic growth in East African Community states. However, population growth

Article DOI: https://doi.org/10.37284/eajbe.8.1.3030

negatively affects GDP (*-14.692, p=0.058*), supporting Bucci & Raurich (2015) and Bucci *et al*. (2018), who argue that high population growth can dilute per capita human capital investment, leading to lower economic performance. Additionally, technological progress initially reduces GDP (*-0.956, p=0.063*) but becomes positive in the long run, suggesting implementation inefficiencies before productivity gains materialise, a notion supported by Huang (2016), who emphasises that technology-driven growth depends on human capital accumulation.

The Granger causality test results reveal a bidirectional causal relationship between GDP and population growth, meaning GDP influences population changes, and population growth, in turn, affects economic expansion. Furthermore, gross capital formation and population growth significantly drive GDP growth, while technological progress does not exhibit a strong short-run causal effect on GDP. These findings align with Bucci, & Prettner (2018) and Huang (2016), who argue that economic growth and demographic changes are interconnected but depend on institutional and technological advancements. Additionally, Jafrin *et al*. (2021) and Mankiw & Weil (1992) find that demographic dividends can contribute to economic expansion in emerging economies. This study suggests that population growth alone may not drive productivity gains unless paired with capital and technological investments. However, Bucci, & Prettner (2018); Mohsin *et al*. (2022); and Tang, & Rosidi (2025) emphasise that endogenous technological change can offset the dilution effects of population growth, which contrasts with this study's findings that technological progress initially hampers GDP.

Regarding the applicability of the Solow-Swan model, the Johansen cointegration results confirm that gross capital formation positively influences economic growth (*1.092, p <0.01*), supporting the model's prediction that capital accumulation is a key driver of long-term economic growth. Furthermore, technological progress significantly influences GDP (*5.711, p<0.01*), further validating the model's emphasis on technological advancement for sustained growth. These findings align with the Solow-Swan model, as gross capital formation and technological progress play vital roles in shaping the economic growth trajectory (Heintz & Folbre, 2022; Agbeyangi *et al*., 2024).

CONCLUSION, POLICY IMPLICATIONS & LIMITATION

Conclusion

This study examined the effects of population growth, capital formation, and technological progress on economic growth in Tanzania, explored their causal relationships, and tested the applicability of the Solow-Swan growth model. The findings reveal that gross capital formation significantly drives economic growth, while population growth has a negative impact, and technological progress initially hampers GDP before contributing positively in the long run. The Granger causality test confirms a bidirectional relationship between GDP and population growth, while gross capital formation has a significant unidirectional impact on economic growth. Additionally, the Solow-Swan model is applicable in Tanzania, as capital accumulation and technological advancement align with the model's predictions as the main drivers of long-term growth. These results emphasise the importance of efficient investment in capital, strategic population management, and better technological adoption strategies to ensure sustainability.

Policy Implications

The findings highlight the need for strategic policies to enhance capital formation, manage population growth, and improve technological adoption for sustainable economic growth in Tanzania. To strengthen capital accumulation, the government should prioritise infrastructure development, industrial investment, and human capital expansion

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while promoting foreign direct investment (FDI) and private sector participation in capital-intensive industries. Additionally, policies aimed at expanding access to financial services, improving credit markets, and fostering entrepreneurship can further boost productive investment and economic stability. Managing population growth requires investments in education, healthcare, and family planning programs to improve human capital while developing labour market policies that ensure the growing workforce is effectively absorbed into productive sectors.

Technological progress should be prioritised through increased investment in research and development (R&D), digital infrastructure, and education to enhance innovation and productivity. Encouraging technology transfer, incentives for innovation, and private sector collaborations can accelerate the adoption of modern production methods, particularly in agriculture and manufacturing. Additionally, strengthening institutional and economic reforms, such as reducing bureaucratic barriers, improving governance, and creating an enabling business environment, is crucial to attracting investment and fostering long-term growth. By implementing these policies, Tanzania can optimise capital accumulation, address demographic challenges, and enhance the role of technology in driving economic transformation.

Limitations and Future Research

Despite some limitations, this study provides robust and reliable insights into Tanzania's economic growth dynamics. Common challenges, such as data inconsistencies and the use of proxies for technological progress, were effectively managed. The use of VECM and Granger causality tests ensured methodological rigour, capturing both short-run and long-run relationships. While context-specific, the findings show strong internal validity and contribute meaningfully to growth literature in developing economies, providing a solid foundation for future research to build upon using broader datasets, nonlinear approaches, and refined measures of technological

Author's Contributions

S.K.M. drafted the introduction and carried out the data analysis. J.A.S. developed the methodology and data interpretation. M.F.L. contributed to the literature review and manuscript editing. All authors read and approved the final version of the manuscript.

Disclosure statement

The author declares no conflict of interest.

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