ARAB ECONOMIC
& BUSINESS JOURNAL

Volume 15 | Issue 2 Article 4

Effects of Technological Progress and Productivity on Economic Growth in Uganda: A Generalized Least Squares Approach

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Recommended Citation

Alani, Jimmy; Yawe, Bruno; and Mutenyo, John (2023) "Effects of Technological Progress and Productivity on Economic Growth in Uganda: A Generalized Least Squares Approach," *Arab Economic and Business Journal*: Vol. 15 : Iss. 2 , Article 4.
Available at: https://doi.org/10.38039/2214-4625.1033

RESEARCH ARTICLE

Effects of Technological Progress and Productivity on Economic Growth in Uganda: A Generalized Least Squares Approach

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Abstract

The paper makes use of the generalized least squares method to examine the effects of technological progress and productivity on economic growth in Uganda during the 1970 to 2020 period. Data employed in conducting empirical analyses were collected from the United Nations data bank. The paper is based on the neoclassical growth model and Cobb−Douglas production function with decreasing returns to scale because production often takes place within the feasible region of production. Therefore, we focus on the range of diminishing (but non−negative) productivity of the factors of production. We also examine the effects of some determinants of technology (e.g., output, innovation, capital, labor, capital productivity, labor productivity, household consumption, investment spending, government spending, exports and imports) on technological progress in Uganda during the given period. The paper is important because previous research works tended to focus more on production with constant returns to scale and increasing returns to scale of factors of production, but less on decreasing returns to scale of factors of production. Yet the production function with increasing returns to scale of factors of production operates, outside the feasible region of production. We find that the increase in the growth of technology, capital, labor and innovation could have boosted the economic growth, while, the increase in capital productivity and labor productivity could have had negative consequences on economic growth in Uganda, during the given period.

Keywords: Technological progress, Innovation, Economic growth, Generalized least squares method, Aggregate profits

1. Introduction

The paper examines the “Effects of Technological Progress and Productivity on Economic Growth in Uganda by Using a Generalized Least Squares Approach.” The time period that the study focuses on runs from 1970 to 2020. Data for empirical analyses were collected form the United Nations Database. The paper also attempts to (a) estimate the innovation index for Uganda based on the relationships between levels of technology, capital productivity and labor productivity, (b) examine the causes and consequences of technology, and input productivity; and (c) estimate the actual levels of capital, labor, technology and innovation in Uganda during the given period. In the 1960s, Uganda government had five−year development plans. But in the 1970s and early 1980s political and social unrest disrupted the development plans.

According to literature, often economic growth is mainly attributed to growth in physical capital, human capital and technology. Before 1960 emphasis on economic growth was attributed to the investment in physical capital. Meanwhile, in the 1960s, economic growth began to be examined in terms of human capital approach (Bowman, 1962; Denison, 1967; Schultz, 1961). Since 1960, the human capital has become the core issue of the new growth or the endogenous economic growth. The new economic growth aims at explaining the economic

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Received 10 February 2023; revised 21 May 2023; accepted 22 May 2023.

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https://doi.org/10.38039/2214-4625.1033

growth of developing and developed countries (Barro, 1991; Barro & Sala-i-Martin, 1995; Lucas, 1988; Romer, 1986, 1990a, b; Sissoko et al., 2018).

Proponents of the endogenous economic growth argue that the standard neoclassical model has shortcomings. They, believe that the neoclassical model ties economic growth to diminishing returns. As a result, they reason that due to diminishing returns, the developing economies would grow faster than the developed countries. The neoclassical approach predicts very low levels of physical capital stocks would induce capital flows from developed countries to developing countries. Their empirical research has rejected both implications of the neoclassical approach (Sissoko et al., 2018).

The attack launched on the neoclassical growth model may be baseless because, often production takes place within the feasible region of production. Therefore, by rejecting the neoclassical model would imply that the endogenous growth model operates within the infeasible region of production that may tantamount to frequent economic depressions. The national innovation systems approach stresses that the flows of technology and information among people, enterprises and institutions are key to the innovative process. Innovation and technology development are the results of a complex set of relationships among actors in a system composed of enterprises, universities and government research institutes.

The policy-makers, argue that understanding the national innovation system is important in identifying key points for enhancing innovative performance and overall competitiveness. It can assist in identifying abnormalities within the system, among institutions and their interactions with government policies, that can inhibit technology development and innovation. Technology performance analysis has traditionally focused on inputs like (a) expenditures on research and development, (b) the number of research personnel, and (b) outputs like patents. These measurements are standardized across OECD countries (OECD, 1996). However, over time it has become evident that these approaches have limitations.

These indicators are important sources of information about the content and direction of technological efforts. But their ability to measure the general “innovativeness” of an economy is limited. Meanwhile, conventional indicators do not offer convincing explanations of trends in innovation, growth and productivity. Although the neoclassical model does not provide how various actors in a country interact in the innovation process, it presents how various factors and sectors interact and linkages among those involved in technology development and translating the inputs into outputs (OECD, 1997, pp.7–9).

The paper contributes to knowledge by using the Cobb-Douglass production function to estimate levels of capital, labor, capital, capital productivity, labor, labor productivity, economic profits, total costs of production, technology, actual technology and innovation. Our empirical findings show that among the drivers of economic growth in Uganda, both innovation and technological progress had the greatest income elasticity during the 1970 to 2020 period.

Secondly, in the paper we find that yearly growth in capital stock equals yearly growth in investment, while annual growth in household consumption equals annual growth in labor. The third contribution that we make regards the estimation of the influence on technological progress by growth in household consumption, household disposable income, investment spending, government spending, exports, imports, capital productivity, labor productivity, innovation, economic profits, and total factor. Many other relationships are examined as well.

2. Review of literature

Technology is greatly required for enhancing economic growth and boosting employment rate. Technological advancement is important for improving education, health status and elevating the quality of life (Cavallo, 2016). Technology spending and economic growth have a tight relationship when measured by productivity and GDP. A good prediction can be made with some accuracy regarding the effect of decline in technology spending on the overall economy. Technological progress in firms leads to reduction in discretionary spending and generates profits during since more can be produced with less inputs. In the short run labor productivity across the economy falls, since technological innovation is an important component of productivity (Al Akayleh, 2018), since in the short run the relationship between economic growth $\mathrm{dlog}(Y)$ and e.g., labor productivity growth $\mathrm{dlog}(Lp)$ can be represented as follows: $\mathrm{dlog}(Y) = \mathrm{dlog}(L) + \mathrm{dlog}(Lp)$.

By 2025 Saudi Arabia's government spending on technology is estimated to be worth $24.7 billion (SR 93 billion) and it is expected to be the highest in the world, accounting for 21.7% of national spending (Alarabiya News, 2022). Uganda like any other developing country cannot afford this level of government funding on technology. Although Uganda's development strategies and policies stress innovation through science and technology capacity development for various core sectors such as agricultural and manufacturing, its government spending on research and development (R&D) i.e., technology; is less than 2%. Uganda is aiming at developing technology for enhancing its export-oriented led growth strategy that is why it has been supporting funding creative programs at Makerere University, such as the electric Kiira EV motor vehicle. The Kiira EV was expected to go into production in 2018 (Ecuru & Kawooya, 2015).

According to Ayouni et al. (2022), exports of goods and services are the key drivers of economic and social development. Exports has the ability to influence economic growth, and are subject to growth strategies adopted by developing countries. Soltani (2012), analyzes issues of trade openness in the case of Tunisia using OLS method over the period 1975 to 2009 and finds that trade openness exerts a long term significant and positive effect on economic growth. By using the ARDL approach and annual time series data from 1978 to 2009, Hey (2012) finds significant long-run positive relationship between export and economic growth in China (Adedoyin et al., 2022). Saleem et al. (2023) using ARDL approaches and annual time series data from 1973 to 2020 find that Pakistan's economic growth responds positively to export growth and decline (Mamun & Kabir, 2023).

Meanwhile, Goh et al. (2017) shows that exports provide an outlet for local goods and services. Exports are also a source of foreign exchange inflows to cope with demand for imports and government revenues for the financing of the national economy. Moreover, high levels of export enhance employment and reduce poverty.

Reeducation in government revenue could constrain economic growth by limiting the import capacity of capital goods and the inputs needed for enhancing production. Dahmani et al. (2022), examine relationship between international trade and economic growth in Tunisia.

They use cross-section augmented Autoregressive Distributed Lag (CSARDL) model and Granger causality test to a panel of 14 economic sectors over the 1995–2018 period. Their empirical results suggest that trade openness exert a positive significant effect on Tunisia's economic activity (Ayouni et al., 2022). Based on co-integration test with unknown structural breaks and ARDL bound testing, Ayouni et al. (2022) examine the effect of external factors on economic growth in Tunisia by using annual time series data for the period 1976 to 2017.

They find that during the given period imports had negative affect on economic growth while exports promoted economic growth whereby a 1% increase in export growth might have caused economic growth to increase by 0.702%. Therefore, they find that export plays a key role in economic growth of Tunisia. Implying that Tunisia must provide adequate training and infrastructure to ensure the gain of transfers of new technologies. They also recommend import restrictions while allowing for import of equipment and machinery goods that promote production and economic growth (Ayouni et al., 2022).

Since 1947, a significant portion of economic growth has been due to technological progress, and the gap in the technology levels between countries can be primarily explained by the differences in the technological advancement of different countries (Kim et al., 2017). Meanwhile, for almost seven decades, the relationship between technological progress and economic growth has been researched by using several formal models. The traditional neoclassical models similar to Solow (1956) treat technical progress as an exogenous variable. They show how long-run economic growth depends only on exogenous technical progress. Arrow (1962) endogenized technology by assuming learning by doing. His model exhibits a constant technology growth rate and finds that long-run economic growth largely depends on population growth (Loo & Soete, 1999).

Uzawa (1965), Phelps (1966), Conlisk (1967, 1969) and Shell (1967), and others, relate technological progress to economic growth based on labor resources devoted to the development of new technologies and ideas. Romer (1990a, b), Grossman and Helpman (1991a, 1991b), and Aghion and Howitt (1992) all use the endogenous growth model to show that a continued increase in the level of resources spent on the creation of new technologies leads to a persistent increase in economic growth (Loo & Soete, 1999). Technological progress is generally presented as a result of research and development (R&D) activities and intellectual property (Kyzy. 2020).

However, this paper presents technological progress as a total factor of productivity. Technological progress is the engine of economic growth. Technological progress is often viewed as an exogenous outward shift in the production possibility frontier (opportunity set) over time. Forces that cause the outward expansion of the production possibility frontier may be referred to as a technological system (Carlsson & Taymaz, 1991).

Technological progress results in producing more goods with a given quantity of resources or a given quantity of products by using fewer resources. Therefore, technology is the key driver of the efficient allocation of capital and labor in the economy. Hence, higher output depends on technological progress in different industries (Blanchard, 2010; Kyzy, 2020).

Bloom et al. (2019), examine numerous pieces of evidence at different levels of aggregation to confirm that the Romer (1990a, b) specification of the idea production function is misguided. By examining a wide range of evidence involving Moore's law for semiconductors, agricultural innovations, medical innovations that reduce cancer and heart disease mortality, and firm-level data, they find that “research productivity,” the growth rate of research effort over the given period was declining rapidly.

By observing what Romer (1990a) assumes as constant, you can see that this rate is falling rapidly in the data. The solution to this problem is to take the basic Romer (1990a) setup and change it slightly by relaxing the assumption that constant research effort can generate constant exponential growth (Jones, 2019). This same treatment can be administered to the neoclassical model with decreasing returns to scale by deriving the actual technology levels. Our study focuses on the long-run production analysis where the output expansion may be attained by varying all the factors. The term “returns to scale” denotes the changes in output as all factors change by the same proportion (Koutsoyiannis, 1981, p.76—77).

Thus, our study focuses on the feasible region of production where there is diminishing returns to scale and the only production stage for the rational producer (Salvatore, 2006, p, 120). The analyses that neoclassical, endogenous, and evolutionary growth theories advocate point to the same conclusion. These approaches agree on the fact that technological progress is a key driver of economic growth. The neoclassical theory was the first to explicitly analyze the influence of technological progress in growth theory.

The theory exerted a strong influence on a large number of governments to allocate significant funds for scientific and research development, to stimulate the creation and diffusion of innovation. Endogenous growth theory also views technological progress as a key driver of economic growth. This theory emphasizes the importance of externalities, in the form of technological spillover and research and development activities, for the creation and diffusion of innovation. Meanwhile, evolutionary and institutional theories of technological progress is inseparably from the economic and social environment in which they are created and diffused (Sredojevic et al., 2016).

The new growth theory has two central assumptions based on the Solow (1956) model. One, is that technological progress is exogenous, and the other is that the same technological opportunities are available in all countries. The Solow (1956) model assumes a narrow concept of decreasing returns to scale or a broad concept of constant returns to scale. In order to understand the determinants of long run growth based on learning-by-doing or investment in human capital and new technologies, the new growth models treat technology and knowledge as economic goods (Jovanovic, 1995). New growth models differ according to the mechanism employed to endogenize the effect of technical progress on growth. The mechanisms in early models of Romer (1986) are dynamic externalities at the aggregate level, where technology is endogenously provided as a side-effect of private investment decisions (Mayer, 1996). Romer (1986) assumes that the stock of knowledge of a firm, increases in proportion to the firm's expenditure on research and development.

Meanwhile, spillovers from these private investments increase public knowledge. According to Romer (1986), technological change is endogenized, since in his model long-term growth is driven primarily by the creation of new knowledge by forward-looking, profit-maximizing, private agents. He postulates, investment that creates new knowledge displays diminishing returns. But due to knowledge spillovers, the production of goods from new knowledge exhibits increasing returns. Since new knowledge is produced from investment with diminishing returns, each profit-maximizing private agent who invests in knowledge creation faces an optimal upper limit to his investment (Mayer, 1996).

The Cobb—Douglas functions together with all their modern developments are included under the cover of the New Growth Theory (NGT). The most important contributions to the NGT are those of Romer (1990a, b), Aghion and Howitt (1992), Grossman and Helpman (1991a, b). Unlike in the Solow (1956) model, in the works of these researchers, growth is endogenously generated by the R&D activity. Thus, any increase in level of resources allocated to the R&D sector triggers an increase in the economic growth rate. The NGT views technological progress as a result of economic processes.

While previous theories treat technology as a product of nonmarket forces and as exogenously given, the NGT internalizes technology in models that show how markets are functioning and how knowledge and technology, unlike physical objects, are producing increasing returns as a driving force of economic growth (Zaman & Goschin, 2010).

The proponents of the new growth theory explicitly modeled knowledge as an output quality of the research-development sector and proved that the introduction of the human capital changed the production function into one with increasing returns; contrary to the neoclassical conclusions of the diminishing-returns technology. The aggregate production function in the NGT differs from the neoclassical one. In the NGT production function, human capital H enter as a new factor of production (the augmented Solow model), apart from the physical capital K and labor : $Y = F(K, L, H, A)$. Meanwhile, in the NGT, H is no longer a constant, because it is a function of the stock of knowledge from the R&D that continues to offset the diminishing returns of the other inputs by increasing marginal productivity (Romer, 1986; Zaman & Goschin, 2010).

Empirical literature shows that Al-Refai et al. (2016) estimated the effects of technological development on the industrial sector in Jordan by using Cobb Douglas production and Vector Error Correction Model (VECM) technique. They conclude that in Jordan during the period (1990–2014), technological development had a positive effect on the industrial sector. Al-Fahdawy and Al-Jumaily (2017) estimated the effect of technological progress in agriculture of Iraq. Their finding shows that technological progress had positive influence on the sector. Nassar (2019) examines the influence of intellectual capital on corporate performance of the Wholesale and Retail trade companies listed in Borsa Istanbul. The study concludes that Turkish wholesale and retail trade companies are paying good attention to the use of the Intellectual capital, especially human capital in the company (Alzyadat & Almusalamani, 2021).

Dastane (2020) shows that technological change and information technology (IT) infrastructure positively and significantly affects the organization's productivity. Muchdie and Narmaditya (2019) finds a positive and strong relationship between technology index and domestic trade in the Baltic States. Meanwhile, Alzyadat and Almusalamani (2021) employ the Autoregressive Distributed Lag (ARDL) technique with time series data for the 2005 to 2019 period, to examine the role of technological progress in the distribution sector of Saudi Arabia. Their results show a long run relationship between the production of wholesale trade sector and in Saudi Arabia and factors of production: labor, capital and technology. They find the wholesale and retail sector trade to be operation under increasing returns to scale, while the technology elasticity to retail and wholesale production stands at 4.62.

Although Romer (1986) succeeds in endogenizing technological progress, his model suffers from some weaknesses, since in his model technological progress remains merely a secondary result of the company's economic activities, and definitely not in line with actual events (Sredojevic et al., 2016). Therefore, our major contribution is properly endogenizing technological progress in the Solow neoclassical Cobb–Douglas production function having increasing returns to scale, something that Romer (1986) and other scholars failed to do well.

This model presents output (Y) as a function of actual level of technology (A_c), labor hours (L) and capital stock (K) as follows: $Y = A_c^{\omega} K^{\alpha} L^{\beta}$, where $\omega > 1$ is a parameter of increasing return to scale on the technology, while α, β are returns to scale on capital and labor respectively such that $0 < \alpha + \beta < 1$.

Our second major contribution involves the effect of labor productivity on economic growth. According to the neo-classical theory of economic growth principle, technological progress causes an increase in the income per capita (i.e., labor productivity) and stimulates savings and investments, thus causing an increase in real GDP. Therefore, if technological progress stops, economic growth also ceases.

Schumpeter (1934) is known to be first economist to defend the postulation that technological development has positive effects on economic growth. According to Schumpeter (1934) technological progress is an evolutionary process involving creative destruction, weakening sectors and development of new technologies as well as new industries in the economy (Justman & Teubal, 1991). The theoretical approach advanced by Schumpeter (1934), treats technology as an external concept very much like in neo-classical approach where firms buy proper technologies by monitoring the technological advances, production of new goods, opening of new markets, making new market organizations and finding new sources of raw materials (Caliskan, 2015).

In contrast to the neo-classical theory of economic growth principle, we advance an endogenous growth theory that growth in labor productivity may cause the same amount of output to be produced by fewer units of labor. Thus, leading to the displacement of labor from the production process, leading to reduction in economic growth. Similarly, growth in capital productivity may cause the same amount of output to be produced by fewer units of capital.

Thus, leading to the displacement of capital from the production process, resulting in economic growth decline. Moreover, by using the identity theories $(Y \equiv KK_p, Y \equiv LL_p)$ and the neoclassical production function $(Y = K^{\alpha}L^{\beta})$, our study is able to demonstrate that growth in both technological progress and innovation individually have the potential of increasing growth in labor productivity, capital productivity, labor and capital. Our third major contribution involves endogenizing innovation in the neoclassical production function. While critiquing the neoclassical theory, institutional and evolutionary theorists explain the growth phenomenon by promoting the concept of national innovation system.

The major assumption of the national innovation system concept postulates that the economic growth of the country is possible with technological progress. It is not predominantly affected by the quantity of research and development resources. But affected by the quality of the organization and efficiency of management of these resources at the microeconomic and national levels (Blanchard & Johnson, 2005, p. 258; Sredojevic et al., 2016).

Therefore, the capacity to manage technological changes is primarily an endogenous social process. In the study we endogenize innovation and estimate its effects on economic growth and other macroeconomic variable for the case of Uganda. In particular we measure innovation (Z) in terms of $Z = Y^{1-\alpha-\beta}$. Our fourth major contribution involves the effects of technological progress on labor. According to Schulte and Howard (2019), technology will create less work, render workers redundant or terminate work by replacing workers. Another main view is that technology creates plenty of opportunities for workers and improves upon economies.

Historical evidence shows that technology changes work-style, and the number of jobs created to exceeds the number of jobs lost. Current evidence on technological displacement, show that there is a growing commentary support for the occurrence of technologically induced unemployment (Brynjolfsson & McAfee, 2014; Frey & Osborne, 2013). Several of such cases confirm that displacement is the result of increased productivity leading to reduction in labor demand and wages in some sectors (Acemoglu & Restrepo, 2014, 2018). However, technology has various counteractive effects that boost employment, in terms of increased capital accumulation and the creation of new tasks in which labor has a comparative advantage relative to machines (Acemoglu & Restrepo, 2014, 2018; Bessen, 2019).

Numerous studies show positive effects of labour productivity on economic growth and development (Wu, 2013; Zulu, 2015). The main reason for the recent decline in growth rates of real GDP in Japan and Germany is the decrease in the growth rate of labor productivity (Nakamura et al., 2018). Meanwhile, there are claims thar labor productivity growth powers economic growth (Moss et al., 2020).

In contrast, our theoretical analysis and empirical findings show that growth in labor productivity (L_p) as well as capital productivity (K_p) lead to decline in economic growth as follows: $Y = (AK_p^{-\alpha}K_p^{-\beta})^{(1/(\alpha+\beta))}$.

There is a high correlation between the economic growth rate and the decrease in unemployment rates. An increase in the growth rate increases the employment rate or decreases the unemployment rate. In economic literature Okun law represents the relationship between economic growth and unemployment. Experimental research based on Okun law shows that there is an inversely proportional relationship between economic growth and growth in unemployment. Okun (1962) shows that there is a reciprocal correlation between unemployment and economic growth. He finds that if unemployment fell by (1%), it could be due to an increase in real gross domestic product (RGDP) by (3%) and vice versa (Hala & Huseyin, 2021).

But when an increase in the real output (Y) growth occurs, an increase in employment is attained. We believe that increase in labor productivity may cause decline in employment, but increase in unemployment since rapid increase in labor productivity may squeeze labor out of the production process.

Yet, there is and relationship between labor (L) and labor productivity (Lp) as follows: $L = Y/Lp$, and real output as a function of technology (A), Kp, Lp may be represented as follows: $\log(Y) = [1/(1-\alpha-\beta)][\log(A) - \alpha\log(Kp) - \beta\log(Lp)]; \quad 0 < \alpha + \beta) < 1$.

Imported capital goods, machinery and intermediate production inputs can improve growth through the diffusion of new technologies (Grossman & Helpman, 1991; Mazumdar, 2001). Some imported goods are beneficial to countries that are in the early stages of development. Meanwhile, trade openness promotes economic growth; by enhancing exports and increase productivity as well as easing the country's foreign exchange constraints. Thus, enabling the country to acquire imports with advanced technology (Balasubramanyam et al., 1996; Ayouni et al., 2022).

Exports of goods and services are key to economic and social development because of their ability to influence economic growth. They are subject to growth strategies adopted by developing countries. According to Goh et al. (2017) exports constitute an outlet for local goods and services. Exports generate foreign exchange inflows to meet demands for imports and generating government revenues needed for the financing of the national economy. Meanwhile, technological progress has been considered to have a permanent effect on growth in the host country through technology transfer and spillover effects (Borensztein et al., 1998; De Mello, 1997; Ayouni et al., 2022). However, various literature agree that export plays a significant role in the economic growth of developing countries, and its effect depends on the number, quality, price, and volume of exports of different types of products (Jordaan and Eita, 2007; Mamum & Kabir, 2023).

3. Theoretical framework

Like in basic theory of production our study concentrates on the usual microeconomic range of output over which the marginal products of factors, although positive decrease. That is, over the range of diminishing (but non−negative) productivity of the factors of production. Alternatively, our study focuses on the theory of production that concentrates on levels of employment of the factors over which their marginal products are positive but decrease (Koutsoyiannis, 1981, p.71).

The study also focuses on the long run analysis of the production where expansion of output may be attained by varying all the factors. The term "returns to scale" denotes the changes in output as all factors change by the same proportion (Koutsoyiannis, 1981, pp.76−77). Thus, our study focuses on the feasible region of production where there is diminishing returns to scale and the only production stage for the rational producer (Salvatore, 2006, p, 120). Economic analysis often employs the Cobb−Douglas production function given by

$$Y=AK^{\alpha}L^{\beta},\,(A>0;0<\alpha;\beta<1) \tag{3.1}$$

Here Y is the quantity of output in physical units, K is the quantity of capital, and L is the amount of labor used. Meanwhile, α (the output elasticity of capital) measures the percentage change in Y for a 1 percent change in K while L is held constant.

Similarly, β (the output elasticity of labor) measures the percentage change in Y for a 1 percent change in L while K is held constant, and β is an efficiency parameter reflecting the level of technology (Dowling, 1999, p.116). In our study we make use of the generalized Cobb−Douglas function that exhibits decreasing returns to scale such that $0<\alpha+\beta<1,$ where $\alpha\neq 1-\beta$.

Manipulation of Equation (3.1) provides an expression of output (Y) as a function of level of technology (A) labor productivity (L_p) and capital productivity (L_p) as follows:

$$Y=\left[AK_p^{-\alpha}L_p^{-\beta}\right]^{\frac{1}{1-\alpha-\beta}}. \tag{3.2}$$

Here α and β are parameter of returns to scale on capital and labor respectively. Equation (3.2) can be rewritten as a function of level of technology as a function of output, labor productivity and capital productivity as follows:

$$A=Y^{1-\alpha-\beta}K_p^{\alpha}L_p^{\beta}. \tag{3.3}$$

Alternatively, Equation (3.2) can be rewritten as a function of level of technology as a product of level of innovation (Z), labor productivity and capital productivity as follows:

$$A=ZK_p^{\alpha}L_p^{\beta}. \tag{3.4}$$

Research and Development (R&D) expenditure as a percent of Gross Domestic Product (GD) is one of the variables that can be used to examine and demonstrate the effect of technological progress on economic growth. The OECD collects the Main Statistics and Technology Indicators in its database and uses the R&D as a proxy for technological innovation (Kyzy, 2020). Similarly, in our study we use logarithm of innovation ($\log(Z)$) as a proxy for innovation and logarithm of output ($\log(Y)$) as a proxy for the influence of output on innovation.

Therefore, in our study the innovation index (II) is constant and given by

$$II=\frac{\log(Z)}{\log(Y)}=\frac{\log(Z)}{\log(Y)}=\frac{\log\left(Y^{1-\alpha-\beta}\right)}{\log(Y)}=1-\alpha-\beta. \tag{3.5}$$

Meanwhile, in our study the level of innovation is measured by

$$Z=Y^{1-\alpha-\beta}. \tag{3.6}$$

Equation (3.6) gives prior indication that innovation has a dramatic influence on output.

$$Z=Y^{(1/(1-\alpha-\beta)}. \tag{3.7}$$

That is because the value of $(1-\alpha-\beta)$ is positive and close to zero.

Public expenditure on R&D as a percent of national GDP in 19 Sub−Saharan Africa is less than 0.3 percent. In particular public expenditure on R&D as a percent of national GDP in Uganda is only 0.2 percent (Mugabe, 2011; SARUA and UNESCO, 2007).

Furthermore, the product of (a) labor and labor productivity, (b) capital and capital productivity and (c) output are always identical and are always equal to the Cobb–Douglas production function and can be represented as follows:

$$Y \equiv KK_p \equiv LL_p \equiv AK^{\alpha}L^{\beta}. \tag{3.8}$$

We use these identities to build and depict the influence of technology on capital, labor, capital productivity and labor productivity. The eight models that could be derived from Equation (3.8) can be represented in logarithm form as follows:

$$log(K) = \frac{1}{1-\beta} log(A) - \frac{\beta}{1-\beta} log(L_p) - \frac{1}{1-\beta} log(K_p). \tag{3.9}$$

$$log(K_p) = log(A) - (1-\alpha) log(K_p) + \beta\, log(L). \tag{3.10}$$

$$log(L) = \frac{1}{1-\alpha} log(A) - \frac{\alpha}{1-\alpha} log(K_p) - \frac{1}{1-\alpha} log(L_p). \tag{3.11}$$

$$log(L_p) = log(A) - (1-\beta) log(L_p) + \alpha\, log(K). \tag{3.12}$$

$$log(K) = log(A) + \beta\, log(L) - (1-\alpha) log(K_p). \tag{3.13}$$

$$log(K_p) = log(A) - (1-\beta) log(L) - \alpha\, log(K). \tag{3.14}$$

$$log(L) = log(A) + (1-\alpha) log(K) - log(L_p). \tag{3.15}$$

$$log(L_p) = log(A) - (1-\alpha) log(K) - \alpha\, log(L). \tag{3.16}$$

The notion that output (Y) is product of technology (A) and total factor TF gives rise to level of technology (A) as a function of household consumption (CN), investment spending (I), government spending (G), export (X) and import (M) that can be represented as follows:

$$log(A) = \beta_1\, log(Cn) + \beta_2\, log(I) + \beta_3\, log(G) + \beta_4\, log(X) - \beta_5\, log(M). \tag{3.17}$$

Moreover, given that output (Y) is a function of household consumption (CN), investment spending (I), government spending (G), export (X), import (M) and population (M) (i.e., technology diffusion) this relationship can be represented as follows:

$$log(Y) = \beta_1\, log\left(\frac{Cn}{Po}\right) + \beta_2\, log\left(\frac{I}{Po}\right) + \beta_3\, log\left(\frac{G}{Po}\right) + \beta_4\, log\left(\frac{X}{Po}\right) - \beta_5\, log\left(\frac{M}{Po}\right) + \beta_6\, log(Po). \tag{3.18}$$

Finally, in our study we endogenize the level of endogenous technology (AR) as follows:

$$Y = (AR)^{\lambda} K^{\alpha} L^{\beta}. \tag{3.19}$$

Here, λ is defined as the output elasticity of technology that has to estimated. From Equation (3.19), it can be discerned that level of technology can be represented as follows: $A = (AR)^{\lambda}$ or as $AR = A^{(1/\lambda)}$. (3.20)

Higher school education (H) input is the driving force behind technological progress (A). And it is this technological progress that enhances the capital productivity (K_p), and labor productivity (L_p). As a result, the increase in the productivity of inputs causes the firms to produce same quantity of output (Y_1) with less inputs. Thus, causing the isoquant to shrink inwards as represented by the arrow AB shown in Fig. 1 below.

When the firms produce the same amount of output by using fewer inputs, they realize more profits (π) that can be reinvested by spending more on labor (L_3), capital (K_3), and innovation (Z). And it is this innovation that enables firms to shift their level of production from (Y_1) to (Y_2), i.e., C to D.

4. Methodology

4.1. Generation of capital stock out of investment spending

Most attempts aimed at estimation of capital stocks use similar types of Perpetual Inventory Method (PIM). The PIM capital estimation technique treats capital stock of an economy as inventory. As a result, the inventory (capital) stock increases with capital formation. The PIM proponents assume that once an

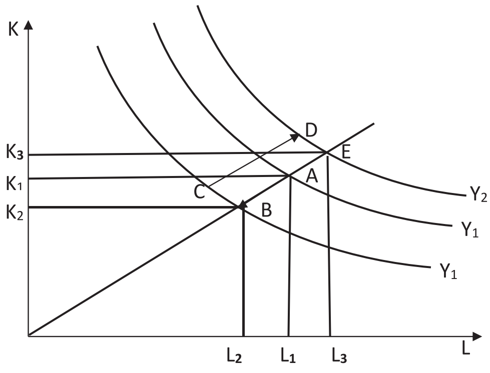

Fig. 1. Interactions among: relationship among technology, productivity, economic profit, innovation, higher education and economic growth as illustrated in Fig. 1 presented below.

investment becomes part of the inventory in the economy, it remains there forever while providing services to the inventory's owner.

As soon as the investment is made, the quantity of services, the investment provides, is at its maximum. Meanwhile, with time the quantity of investments declines, but never falls to zero (Berlemann & Wesselhoeft, 2012).

Therefore, in the PIM model, the annual depreciation rate is taken to be δ_t, implying that the capital–accumulation equation can be expressed as follows:

$$K_t = K_{t-1} - \delta_t K_{t-1} + I_t. \tag{4.1.1}$$

Change in capital stock $(K_t - K_{t-1})$ provides the level of investment spending (I_t) and it represents the flow of output in any given period that is used to maintain or to increase the capital stock in an economy (Sachs and Larrain, 1993, pp.34–35).

$$K_t = K_{t-1} + \mathrm{I}_t. \tag{4.1.2}$$

Meanwhile, the capital stock in period t is the accumulated capital stock during the entire period of capital-stock investments and is represented by

$$K_t = \sum_{i=0}^{t} (1-\delta_t)^i I_{t-(i+1)}. \tag{4.1.3}$$

(Berlemann & Wesselhoeft, 2012).

Solving Equations (4.1.1) and (4.1.2) simultaneously provides

$$0 = -\delta_t \mathrm{K}_{t-1}. \tag{4.1.4}$$

Taking the second partial derivative of Equation (4.1.4) with respect to capital and dividing it by the first derivative with respect to capital gives

$$0 = -\delta_t \frac{\partial(\partial(K_{t-1}))}{\partial(K_{t-1})} = -\delta_t \frac{\partial(I_{t-1})}{I_{t-1}}. \tag{4.1.5}$$

$$\mathrm{Or} = -\delta_t \log(I_{t-1}). \tag{4.1.6}$$

Taking the logarithm of Equation (4.1.5) produces Equation (4.1.6).

$$\log(1) = \log(1) - \log[\delta_t.(\log(I_{t-1}))]. \tag{4.1.7}$$

$$\text{Therefore} \log(1) = -\log[\delta_t.(\log(I_{t-1}))]. \tag{4.1.8}$$

$$\text{Hence } \delta_t = \frac{1}{\log(\mathrm{I}_{t-1})}. \tag{4.1.9}$$

But the PIM method stipulates that at the beginning of period t, capital stock (K_t) can be specified as a function of (a) net capital stock (K_{t-1}) at the beginning of the previous period $t-1$, (b) gross investment in the previous period, (I_{t-1}) and (c) consumption of fixed capital (depreciation) in the previous period (D_{t-1}). The capital stock equation can be expressed as:

$$K_t = K_{t-1} - \mathrm{D}_t + \mathrm{I}_t. \tag{4.1.10}$$

Implying that at equilibrium

$$d(K_t) = -d(K_{t-1}). \tag{4.1.11}$$

Due to old age, the stock of capital wears out and the wearing out process of capital is called depreciation, hereby denoted as D_{t-1}.

Therefore, the change in capital stock $(K_t - K_{t-1})$ is equal to the flow of net investment $(\mathrm{I}_t - \mathrm{D}_t)$ (Sachs and Larrain, 1993, p.35).

$$K_t - K_{t-1} = \mathrm{I}_t - \mathrm{D}_t = \mathrm{I}_t - \mathrm{I}_{t-1}. \tag{4.1.12}$$

$$\text{Hence } \mathrm{D}_t = \mathrm{I}_{t-1}. \tag{4.1.13}$$

It is clear that

$$\delta_t \mathrm{K}_{t-1} = \mathrm{D}_t. \tag{4.1.14}$$

Substitution of Equation (4.1.13) in **(4.1.14)** provides

$$\delta_t \mathrm{K}_{t-1} = \mathrm{I}_{t-1}. \tag{4.1.15}$$

So that substitution of Equation (4.1.8) in **(4.1.15)** gives

$$\mathrm{K}_{t-1} = \mathrm{I}_{t-1} \log(\mathrm{I}_{t-1}). \tag{4.1.16}$$

Implying that given levels of investment spending the respective quantities of capital stock can be generated by the following equation represented by

$$\mathrm{K}_t = \mathrm{I}_t \log(\mathrm{I}_t). \tag{4.1.17}$$

Here it should be noted that growth in capital stock (K_t) is equal to the growth in investment spending (I_t) and the relationship can be represented as follows:

$$\mathrm{d}(\log(\mathrm{K}_t)) = \mathrm{d}(\log(\mathrm{I}_t)). \tag{4.1.18}$$

4.2. Measurement of labor

Having obtained the time series data on the annual short–run capital stock (K_{t-1}), aggregate disposable income (Y_{dt}) and the annual quantities of labour (L_{t-1}) can be generated by using the following formula.

$$L_{t-1} = \left[Y_{dt} \Big/ \left((K_{t-1})^{(API_t)} \right) \right]^{[1/APC_t]}. \tag{4.2.1}$$

Since the short-run marginal propensity to consume (MPC_t) equals short-run average propensity to consume (APC_t). Implying, marginal propensity to invest (MPI_t) and average propensity to invest (API_t) are the same in the short run.

4.3. Measurements of technology and innovation

This study extends the current method of computing the level of innovation by defining it as the residual of the level of technology presented as a function of capital and labour productivity. To define TFP, the Cobb−Douglas version of the production function in use is represented by output (Y) as a function of technology (A), capital (K), labour (L), and parameters α, β (Lipsey & Carlaw, 2004).

$$Y = AK^{\alpha}L^{\beta}. \tag{4.3.1}$$

Where $0 < \alpha + \beta < 1$.

The TFP is calculated by dividing both sides of Equation (1) by the total factor $K^{\alpha}L^{\beta}$ to provide

$$TFP = \frac{Y}{K^{\alpha}L^{\beta}} = A. \tag{4.3.2}$$

Similarly, to define innovation (Z), the Cobb−Douglas version of technology function in use, is represented by the level of technology (A) as the function of innovation (Z), capital productivity (K_p), labour productivity (L_p) and parameters α, β.

$$A = ZK_p{}^{\alpha}L_p{}^{\beta}. \tag{4.3.3}$$

Where

$$Z = Y^{1-\alpha-\beta} = AK_p{}^{-\alpha}L_p{}^{-\beta}. \tag{4.3.4}$$

4.4. Data, data sources and tests

The paper performs linear regression analyses by using the generalized least squares (GLS) method on secondary data collected from the United Nations Data Base on Uganda covering the period 1970 to 2019. Data used in empirical analyses are on aggregate household consumption, investment spending, government spending, exports, imports and aggregate disposable income because they are the two variable that are commonly present in the household consumption function. The t, F, DW and H statistical tests were conducted by comparing the computed t, F, DW and H values with their respective critical values from standard Statistical Tables. The H is the computed t value used in testing for heteroscedasticity by conducting the usual t-tests after multiplying all variables in a regression by vector (V).

5. Presentation and discussion of results

According to Rubi (2008) the Causality Principle states that all real events necessarily have a cause. The principle indicates the existence of a logical relationship between two events, the cause and the effect, and an order between them: the cause always precedes the effect. Thus, we assume that no product is introduced in the economy at the beginning of the year. But at the end of the year the products will have increased from zero up to Y_t level of income. Here we assume that the economy is following the tendency that systems have to evolve towards equilibrium. The increase in products can be described by the flux $J = 1$ accounting for the quantity of output per level of investment spending (I_{t-1}) at the beginning of year Y_t. However, non-equilibrium in the economy establishes the form of this flux as follows:

$$1 = \alpha(Y_t - 0)/I_{t-1} = \alpha Y_t/I_{t-1}. \tag{5.1}$$

Here, α is the marginal propensity to invest. Equation (5.1) can be estimated by rewriting it as

$$1 = \alpha Y_t/I_{t-1} + \epsilon_t. \tag{5.2}$$

By using the GLS technique and the relevant data on Uganda, and conducting linear regression of Equation (5.2), the value of MPI turned out to be 0.155 as shown in Equation (1) below. We estimate returns to scale on capital by MPI because in the long run $d(K) = d(I)$. This relationship arises from the fact that given $K = K_{-1} + I$. So that $d(K) = d(K_{-1}) + d(I)$ provides the expression that equal to $d(K - K_{-1}) = d(I)$, the long run trend of K & I.

$$1 = 0.155028(Y/I_{-1}). \tag{5.3}$$

$t\ 11282\ R^2 = 1.0000\ DW = 1.94$

$N = 47\ Period: 1972 - 2020\ Vector = 1/d(d(Y^2))\ H = 0.02$

To estimate Equation (4.5.7) above we present it in a causal form as follows:

$$1 = \alpha\frac{Y_{dt}}{I_{t-1}} + \beta\frac{Y_{dt}}{C_{nt-1}} + \epsilon_t. \tag{5.4}$$

Thus, by using the GLS technique, relevant data on Uganda, and conducting linear regression of Equation (5.4), the value of MPC turned out to be 0.562 as shown in Equation (5.5).

$$1 = 0.044327(Y/I_{-1}) + 0.562251(Y/C_{n-1}). \tag{5.5}$$

$t\ 35.75\ 70.56$

$$R^2 = 1.0000\; DW = 1.91\; F = 960576\; N = 48$$

$$Period: 1973 - 2020\; Vector = 1 \Big/ d\left(d\left(\left(Y/I_{-1}\right)^2\right)\right)\; H = 0.64$$

We estimate returns to scale on capital by MPI because in the long run at equilibrium household consumption equals to the value of quantity of labor. To prove this, we let the marginal utility of leisure, consumption and labor be denoted by MU_Z, MU_{Cn}, MU_L, respectively. Then the slope of the consumption-leisure indifference curve is the measure of the rate at which a person is willing to give up some leisure time in return for additional consumption, while holding utility constant.

Thus, this slope of the indifference curve can be shown to be given by

$$\frac{dC_n}{dZ} = -\frac{MU_Z}{MU_{Cn}}. \tag{5.6}$$

Meanwhile, the slope of the labor-leisure indifference curve measures the rate at which a person is willing to give up some leisure time in return for additional labor, while holding utility constant. Thus, the slope of this indifference curve can be shown to be given by

$$\frac{dL}{dZ} = -\frac{MU_Z}{MU_L}. \tag{5.7}$$

At equilibrium the marginal rate of substitution (MRS) of consumption for leisure can be equated to the MRS of labor for leisure. Implying that from Equations (5.6) and (5.7) we get

$$-dZ.MU_Z = -dC_n.MU_{Cn} = -dL.MU_L. \tag{5.8}$$

Equation (5.8) can be rewritten in a more convenient form as follows:

$$\frac{dC_n}{dL} = \frac{MU_L}{MU_{Cn}}. \tag{5.9}$$

Therefore, at equilibrium the $MU_{Cn} = MU_L$ implying that $dC_n = dL$. Hence, at equilibrium the quantity of labor equals the quantity of consumption since

$$\int_0^{C_n^*} dC_n = \int_0^{L^*} dL. \tag{5.10}$$

Therefore, at equilibrium $C_n^* = L^*$.

Having obtained the returns to scale on capital and returns to scale on labor we use these two values and the quantities of output, capital and labor to compute the annual values of level of technology by using the formula: $A = Y/(K^{0.155028}L^{0.562251})$.

The relevant regression results got are presented in Equation (5.11) below.

$$d\log Y = 1.001 \mathrm{dlog} A + 0.155 dlogK + 0.562 dlogL. \tag{5.11}$$

$$t\; 16034405\; 17519026\; 39883531$$

$$R^2 = 1.0000\; DW = 1.76\; 1.64 \times 10^{16}\; N = 48$$

$$Period: 1973 - 2020\; Vector = 1 \Big/ d\left(d\left(\left(d(TF)\right)^2\right)\right)\; H = 0.00$$

From Equation (5.11), it can be discerned that a 1 percent increase in technological progress, growth in capital and growth in labor could have caused economic growth in Uganda during the 1973 to 2020 to increase by 1.000, 0.155, and 0.562 percent respectively. Therefore, technological progress has been very important in enhancing economic growth within Uganda during the given period.

Fine (2000) advises that “Progress in economic science often takes the form of explaining what was previously inexplicable. That is, variables which had earlier been treated as exogenous become endogenized. Their values become determined, at least in principle, within an economic model.” We take his advice seriously and transform the exogenous neoclassical production of decreasing returns to scale represented by $Y = AK^{\alpha}L^{\beta}$ to an endogenous neoclassical production function of increasing returns to scale given by

$$Y = AR^{\lambda}K^{\alpha}L^{\beta}. \tag{5.12}$$

where $\lambda > 1$ and it is a case of increasing returns to scale and AR is the actual real level of technology within a given year.

In order to generate the actual real values of level of technology we first make use of causality expressed by Equation (4.4.9) under the theoretical framework. Results obtained after regression of this equation are represented in Equation (5.13) below. From Equation (5.13) it can be observed that a 1 percent increase in the growth of actual real level of technology (AR) might have caused economic growth to increase by $\lambda = 2.418$. Here the relationship between actual real level of technology (AR) and the usual level of technology is given by $AR^{\lambda} = A$. Therefore, the values of the AR were generated by using the formula $AR = A^{1/\lambda} = A^{1/2.418702}$.

$$dlogY = 2.418702 dlogA_{-1} + 0.996935 ddlogY. \tag{5.13}$$

$$t\; 57.62\; 732.77$$

$R^2 = 1.9969 \; DW = 2.07 \; F = 533528 \; N = 48$

$Period: 1973-2020 \, Vector = 1 \Big/ d\left(d\left((TF_{-1})^2\right)\right) H = 0.002$

Having obtained data on all the variables in Equation (5.11) we regress Y on AR, K, L and obtain the results in Equation (5.13). Equation (5.12), is typically a neoclassical growth model with the outlook of an endogenous growth model because it is characterized by increasing returns to scale where:

$$Y = (ARt)^{\lambda}(Kt)^{\alpha}(Lt)^{\beta} = Y = t^{\lambda+\alpha+\beta}AR^{\lambda}K^{\alpha}L^{\beta} = Y = t^{3.136}AR^{\lambda}K^{\alpha}L^{\beta}. \tag{5.14}$$

$$d \log Y = 2.419 \text{dlog} AR + 0.155 dlogK + 0.562 dlogL. \tag{5.15}$$

$t \; 21552 \; 14076 \; 33518$

$R^2 = 1.0000 \; DW = 1.93 \; 2.64 \times 10^{10} \; N = 49$

$Period: 1972-2020 \, Vector = 1 \Big/ d\left(d\left((Y/AR)^2\right)\right) H = 0.576$

According to Thach and Hac (2021), endogenous growth is a way to achieve sustainable economic growth. To verify whether an economy entails endogenous growth, it should be correctly specified by an appropriate production function. Most previous empirical and theoretical studies in growth theory, from Robert Solow to his followers, such as Kenneth Arrow or Paul Romer, have used Cobb–Douglas specifications for analysis. The fundamental weakness of this functional form is that the factor substitution elasticity should always equal one. This constraint makes unclear the role of capital and labor interaction for economic growth process (Thach & Hac, 2021). From Equation (5.15), our findings show that the role played by technological progress in enhancing economic growth is at least thrice the role played by capital and labor combined.

From Equation (5.16), it can be deduced that increase in capital productivity growth and labor productivity growth influence economic growth via their individual effects on technological progress. Technological progress implies producing the same quantity of output with either less amount of labor or capital or both.

The amount by which increase in capital productivity reduces the output via reduction in the amount, of inputs is the same amount by which increase in productivity increases the level of technology. That is during the given period increase in both labor and capital productivity growth reduced output by 2.357 points and increased technological progress by the same amount of percentage points, thus making the parameter of technological progress to become 3.537.

$$d \log Y = 3.537 \text{dlog} AR - 0.548 dlogK_p - 1.989 dlogL_p. \tag{5.16}$$

$t \; 239222 - 19742 - 9135$

$R^2 = 1.0000 \; DW = 1.99 \; 3.48 \times 10^{10} \; N = 48$

$Period: 1973-2020 \, Vector = 1 \Big/ d\left(d\left((TF_{-1})^2\right)\right) H = 0.000$

On examination of Equation (5.17), it appears that three factors might have contributed to the returns to scale on technology. The first two set of factors could have had two equal forces in operation coming from contributions of growth in both capital productivity and labor productivity on technological progress both before the and after the introduction of the growth in the actual real level of technology (AR). The third force could have been the direct influence of technological progress on the economy making a joint force amounting to 8.553 points. We then deduce that both capital productivity and labor productivity could have caused economic growth via both technological progress and growth in the actual real level of technology.

$$d \log Y = 8.553 d \log AR - 0.548 dlogK_p - 1.988 dlogK_p. \tag{5.17}$$

$t \; 20408 - 6262 - 8241$

$R^2 = 1.0000 \; DW = 1.93 \; 2.11 \times 10^{09} \; N = 49$

$Period: 1972-2020 \, Vector = 1 \Big/ d\left(d\left((Y/AR)^2\right)\right) H = 0.569$

The estimation framework in section 4.4 of this paper is made use of in calculation of the influence of innovation on economic growth in Uganda during the given period. Therefore, a 1 percent increase in innovation growth could have caused economic growth to rise by 2.418.

This finding indicates that innovation has been the key driver of economic growth in Uganda.

In the paper the innovation index (II) was estimated by the formula expressed as follows:

$$II = \frac{\log(Z)}{\log(Y)} = \frac{\log\left(Y^{1-\alpha-\beta}\right)}{\log(Y)} = 1 - \alpha - \beta = \frac{28.2721}{100}. \tag{5.18}$$

Thus, during the given period the innovation index for Uganda could have been standing at 28.3 points. This computed index falls with the range of innovation index reported by Global Economy to be as follows: 2014: 31.1, 2015: 27.6, 2016: 27.1, 2017: 25.3, 2018: 25.6, 2019: 20.5, 2020: 20.0 (The Global Economy, 2022).

$$dlogY \,/\, dlogTF = 2.418702 dlogZ_{-1}/dlogTF + 0.996935 ddlogY/dlogTF. \tag{5.19}$$

t 57.62 732.77

$R^2 = 1.0000 \; DW = 2.07 \; F = 533528 \; N = 48$

$Period : 1973 - 2020 \; Vector = 1 \Big/ d\left(d\left((TF)^2\right)\right) \; H = 0.002$

According to Broughel and Thierer (2019), the Solow growth model started a 20th century revolution in growth theory (Solow, 1956). In his model Solow (1956) attempts to explain growth using the basic physical inputs of the production process, labor and capital, including the generic technological change variable that was assumed to grow at a steady rate, regardless of any factors that might change in the model.

$$d \log A = 2.419 \mathrm{dlog} Z + 0.155 dlogK_p + 0.562 dlogL_p. \tag{5.20}$$

t 419589 191339 169710

$R^2 = 1.0000 \; DW = 1.85 \; 1.44 \times 10^{12} \; N = 48$

$Period : 1973 - 2020 \; Vector = 1 \Big/ d\left(d\left((d(Y))^2\right)\right) \; H = 0.244$

Sachs and McArthur (2002) comment that Solow (1956) did not explain the source of technological advancement; and that he just assumed it. Slow (1956), might have just not had time and means to treat his level of technology as a function of other variables.

Also, he might have not had, time to examine the behavior of technological progress within the campus of feasible region of production with reference to the case of diminishing returns to scale. We find that the first three variables that cause technological progress are innovation, capital productivity and labor productivity. Thus, within the given period, a 1 percent increase in innovation advancement could have caused technological progress to rise on average by 1 percent (the same amount).

Meanwhile, a 1 percent increase in growth of capital productivity and labor product, could have cause technological progress to rise by 0.155 and 0.562 percent respectively in Uganda during the 1973 to 2020 period as shown in Equation (20) above. We demonstrate that technological progress depends on a number of factors including the influence of economic growth, capital productivity and labor productivity. Equation (5.21) shows that a 1 percent increase in economic growth, capital productivity growth and labor productivity growth could have caused technological progress to rise by 0.283, 0.155 and 0.560 percent per annum in the country during the 1972 to 2020 period as given in Equation (5.21). The implication of this particular finding is that other variables such as household consumption, investment spending, government spending, exports and imports might have affected technological progress though economic growth. The growth in output might have caused technological progress by availing resources to firms when they purchased and consumed the goods and services produced.

Meanwhile other factors, in particular higher school education, could have been the driving force behind technological progress. They could have caused technological progress by enhancing the capital productivity and labor productivity. As a result, the increase in the productivity of inputs might have caused the firms to produce the same quantity of output with less inputs. Thus, causing the isoquant to shrink inwards. When the firms produced the same amount of output by using fewer inputs, they could have realized more profits that that they could have reinvested by spending more on labor, capital, and innovation. It is this innovation that enables firms to greatly increase their level of production, i.e., causing the isoquant to swing outwards beyond its original position; and the growth begins all over again.

$$d \log A = 0.283 \mathrm{dlog} Y + 0.155 dlogK_p + 0.560 dlogL_p. \tag{5.21}$$

t 1449 655 892

$R^2 = 1.0000 \; DW = 1.88 \; 1.90 \times 10^{08} \; N = 49$

$Period : 1972 - 2020 \; Vector = 1 \Big/ d\left(d\left((Y_d)^2\right)\right) \; H = 0.382$

From Equation (22) it can be discerned that a 1 percent increase in growth of household consumption, investment spending, government spending, exports and imports might have caused technological progress to rise by 0.907, 0.163, 0.084, 0.112, −0.220, and −1.113 percent respectively in Uganda during the 1973 to 2020 period. Thus, stimulation of consumption could have taken place through product innovation. Product innovation as a strategy enables companies to make new products much more meaningful to employees within the organizations. Meanwhile, product innovation can facilitate firms to actively and deliberately participate in the whole innovation process (Dougherty & Hardy, 1996; Ozer, 2005). Zhou (2006) shows that an innovation strategy may be a better choice for companies who intend to compete and win in their local markets because it improves positive outcomes of new product development. Zahra and Covin (1994) demonstrate that a better company is good at its product development when it is enhancing its firm performance (Lee & Xuan, 2019).

Household investment enhances technological progress according to the findings of Roumboutsos and Saussier (2014). They find that within the partnerships between private and public sectors, the private party has great influence on innovation activities and could provide potential incentives for innovation. In such partnership, longer periods of contracts offer greater levels of expected investments. The result is that renegotiation clauses included in such partnerships, transfer fees attached to asset value and concessions also provide further incentives for innovation.

But Roumboutsos and Saussier (2014) argued that private investments are more likely to go to those innovation activities which might have more direct effects on those private parties. For instance, reducing costs of operation and maintenance. Moreover, most of private parties unlikely have big interests in supporting innovation activities which aim to improve social benefits.

Therefore, they usually focus on their investment incremental innovation activities of relatively low risks with regard to their own competence (Lee & Xuan, 2019).

$$\begin{aligned} \mathrm{dlog}A &= 0.907\mathrm{dlog}C_n + 0.1631\mathrm{dlog}I + 0.085\mathrm{dlog}G \\ &\quad + 0.112\mathrm{dlog}X - 0.220\mathrm{dlog}M - 0.113\mathrm{dlog}TF. \end{aligned} \tag{5.22}$$

$$t\ 4.58\ 5.03\ 18.25\ 17.48\ -21.48\ 3.49$$

$$R^2 = 1.0000\ DW = 2.16\ 853838\ N = 48$$

$$\mathrm{Period}: 1973-2020\ \mathrm{Vector}=1d\left(d\left((d(C_n))^2\right)\right)\ H=0.000$$

The reason why private sectors should obtain external financing, among other things, is that loans provided by public sectors, is very important for firms to finance its fixed investments (Mueller and Reize, 2013). Meanwhile, such kinds of investments usually require a lot of capital during irregular intervals in order to make internal financing from cash flow that accrue more continuously. Generally, state support and various kinds of loans are often in favor of young companies. Thus, state support makes contributions to positive outcomes in the structure of existing support mechanism (Simachev et al., 2015).

The state support mechanisms, can offer more widespread use of invested new equipment and enhance worthier investment, depending on the excess depreciation. For the start–up and young firms, such an incentive is very important in case those companies have the ability to build their fixed assets intensively (Lee & Xuan, 2019). Support mechanisms can be in form of giving companies financial support including loans, tax allowances as well as grants. The other support mechanism is through special organizations such as national technology and productivity centres that provide information, education, training and other help to companies with needs (Storey & Tether, 1998).

According to Storey and Tether (1998) there are direct and indirect public measures to intervene and support the whole competitive environment for companies. Among them are regular financial support and technical assistance. Others are government purchases and contracts. Some of the indirect measures that public sectors use to improve innovation environment are (a) improving taxation policy and (b) improving patent systems (Lee & Xuan, 2019).

According to Equation (23), in the long run technological progress could have enhanced employment in Uganda over the 1973 to 2020 period. As a result, a 1 percent increase in technological progress might have caused labor growth to increase by 3.54 percent yearly. The influence of technology on labor could have been positive due to technology diffusion causing replication of industries, as well as spread of knowledge of producing goods and services. However, in the short run technological progress causes job losses. But in the long run the reduction of inputs used in production creates profitability and expansion of firms leading to increase in the demand for more labor in the production process. Meanwhile, growth in labor productivity might have caused reduction in employment because a fall in employment increases the price of labor (wages) and causes some labor to be lost from the production. Similarly, increase in capital productivity leads to reduction in the amount of capital in use and consequently causes labor to have less capital to use, thus leading to a fall in employment.

Evidence from developed countries show the pace of technological change on employment varies by industry (Mark, 1987). Meanwhile, the effect of technology on employment is positive and especially in high-tech sectors enjoying spillover effect of university R&D on employment and high technology employment. The R&D subsidies enhance the number of R&D workers. Also, the R&D offshoring expenditures positively affect skilled employment and the effect of R&D intensity on skilled labor is positive.

On the other hand, according to Ozcan (2019), robotization positively affects employment. Numerous studies generally find positive impact of technology on employment. But few studies find that technology increases unemployment (Feldmann, 2013). Others find no relationship between technology and employment for developed countries (Matuzeviciute et al., 2017; Celik, 2020).

Unlike the developed countries, there are few studies about this issue on the developing countries. Bogliacino and Vivarelli (2012) for Brazil, Conte and Vivarelli (2011) for the 23 developing countries find that the technology positively affects employment. Cirera and Sabetti (2016) find that the impact of technology on employment is positive, especially low-income countries and the African region, using firm-level data. However, a few studies find that technology has no impact on employment (Lundin et al., 2007) or it has negative impact on employment (Jenkins, 2008) for developing countries.

Mitra and Jha (2016) provide evidence that there is no positive relationship between R&D and productivity. But the elasticity of R&D employment is positive in a few of industries of India or it has negative impact on employment (Jenkins, 2008) for developing countries (Celik, 2020).

$$d\log L = 3.539 \mathrm{dlog} A - 0.546 dlogK_p - 2.974 dlogL_p. \tag{5.23}$$

$t\ 2390 - 1582 - 1562$

$R^2 = 1.0000\ DW = 1.77\ 3508664\ N = 49$

$Period: 1972 - 2020\ Vector = 1 \Big/ d\left(d\left((L_{-1})^2\right)\right)\ H = 0.125$

Equations (23) and (24) reveal that by substituting capital for capital productivity causes a reduction in the technology coefficient from 3.539 to 2.285, thus implying that increase in productivity is as a result of technical progress. Also, from equation (13) it can be deduced that labor productivity enhances technical progress by the same amount (2.28) that it reduces growth in labor. The second deduction is that there is a direct positive relationship between capita and labor since a 1% in capital growth leads to 0.353% increase in labor growth.

$$d\log L = 2.285 \mathrm{dlog} A + 0.354 dlogK - 2.284 dlogL_p. \tag{5.24}$$

$t\ 13412\ 8246 - 6609$

$R^2 = 1.0000\ DW = 1.98\ 2.43 \times 10^{09}\ N = 48$

$Period: 1973 - 2020\ Vector = 1 \Big/ d\left(d\left((K_{-1})^2\right)\right)\ H = 0.010$

Equations (24) and (22) show that growth in labor could have caused economic through capital productivity because the amount by which labor influences capital productivity (KP) is the same amount (0.550) by which labor influences output. The relationship between capital productivity and capital is negative since a 1 percent increase in capital growth causes capital productivity growth to rise by −0.844 percent as given in Equation (25). But, from Equation (25) it can be deduced that technological progress had positive influence on KP.

$$d\log K_p = 1.008 \mathrm{dlog} A + 0.559 dlogL - 0.844 dlogK. \tag{5.25}$$

$t\ 994\ 2441 - 5869$

$R^2 = 1.0000\ DW = 1.76\ 2.32 \times 10^{12}\ N = 48$

$Period: 1973 - 2020\ Vector = 1 \Big/ d\left(d\left((d(TF))^2\right)\right)\ H = 0.123$

On comparing Equations (26) and (27) we find that technological progress exerts less influence on capital productivity growth than it does on capital growth. This situation could be due to the fact that the coefficient (3.539) on technological progress is that of level of innovation composed of technological innovation (1.000) and process innovation (2.539). Moving from Equation (26) and (27), when capital productivity is substituted for capital the coefficient on technology increases from 2.286 to 3.539, thus implying that capital productivity is generated by technological progress. From Equations (26) and (27) it can be seen that there is a negative influence of capital on labor productivity (LP) and vise-versa. Too, in the long run there is a negative effect between and capital as well as between LP and KP.

This could be due to the fact that increase in price of labor (productivity of labor) causes producers to use more capital and consequently increase the price (productivity) of capital.

$$d\log K_p = 0.286\text{dlog}A - 1.273dlogL_p - 0.646dlogK. \tag{5.26}$$

$t\,2507 - 1442 - 1698$

$R^2 = 1.0000\; DW = 1.76\; 8.09\times 10^{11}\; N = 48$

$Period: 1973 - 2020\; Vector = 1\Big/ d\Big(d\Big((TF)^2\Big)\Big)\; H = 0.150$

According to Equation (27) growth in productivity of both capital and labor have negative consequences on capital growth. This implies that the combination of influence of technological progress, capital productivity growth and labor productivity growth give rise to the influence of growth in innovation on capital.

$$d\log K = 3.539\text{dlog}A - 1.548dlogK_p - 1.971dlogL_p. \tag{5.27}$$

$t\,3163 - 1698 - 780$

$R^2 = 1.0000\; DW = 1.76\; 3.39\times 10^{11}\; N = 48$

$Period: 1973 - 2020\; Vector = 1\Big/ d\Big(d\Big((TF)^2\Big)\Big)\; H = 0.001$

In Equation (28) it can be discerned that technological progress increases capital stock growth by the same amount by which capital productivity reduces capital stock growth. Therefore, growth in labor appears to have affected economic growth strictly through growth in capital stock. The returns to scale of labor on output, thus could have been: 0.66. Meanwhile, according to Equation (13), in the short run the returns to scale on labor in output could have been 0.35. Therefore, the notion of constant returns to scale appears to have been, in operation in the short run, while the idea of decreasing returns to scale appears to happen in the long run.

$$d\log K = 1.194\text{dlog}A - 1.184dlogK_p + 0.663dlogL. \tag{5.28}$$

$t\,1192 - 5869\; 1727$

$R^2 = 1.0000\; DW = 1.76\; 1.66\times 10^{12}\; N = 48$

$Period: 1973 - 2020\; Vector = 1\Big/ d\Big(d\Big((TF)^2\Big)\Big)\; H = 0.81$

The relationship between labor and labor productivity is always negative. This claim is supported by evidence given in Equation (18) that a 1 percent increase in labor growth could have caused labor productivity to rise by −0.438 percent per annum. Capital growth could have affected output growth through labor productivity growth. This finding is supported by the evidence in Equation (29) where a 1 percent increase in capital growth might have caused productivity growth to be 0.155 per annum. At the same time Equation (29) shows that a 1% increase in capital growth might have caused output growth to rise by 0.155 per annum.

$$d\log L_p = 1.000\text{dlog}A - 0.438dlogL + 0.155dlogK. \tag{5.29}$$

$t\,13507 - 13363\; 19763$

$R^2 = 1.0000\; DW = 1.99\; 9.82\times 10^{07}\; N = 48$

$Period: 1973 - 2020\; Vector = 1\Big/ d\Big(d\Big((TF_{-1})^2\Big)\Big)\; H = 0.274$

In Uganda during the given period a 1% increase in technological progress, labor and capital productivity growth could have caused labor productivity to rise by 1.183, 0.335 and −0.183 percent respectively annually as shown in Equation (30). The result indicates that growth in capital productivity and labor have negative consequences on labor productivity growth. Thus, labor growth remains the major cause that could have affected labor productivity.

$$d\log L_p = 1.184\text{dlog}A - 0.335logL - 0.183dlogK_p. \tag{5.30}$$

$t\,10160 - 10300 - 8044$

$R^2 = 1.0000\; DW = 1.99\; 5.48\times 10^{07}\; N = 48$

$Period: 1973 - 2020\; Vector = 1\Big/ d\Big(d\Big((TF_{-1})^2\Big)\Big)\; H = 0.275$

The study finds that between 1973 and 2020 technological progress had a dramatic influence on aggregate profits in Uganda.

During the given period a 1 percent increase in technological progress and total factor productivity could have caused aggregate profit growth to rise on average by 4.634 and −0.420 percent per annum respectively as shown in Equation (31) below.

Technological progress drives up productivity of both capital and labor, reduces costs of production and increases profitability. This finding for instance is in agreement with Kraus (2021, p.6) that the most profitable buyouts by a foreign company in Israel, is related to technology companies.

These companies were as follows: (a) Mobileye (US \$15.3 billion), acquired by Intel in 2017 (Mobileye, Wikipedia, 2021), (b) Mercury (US \$4.5 billion), acquired by HP in 2016 (Mercury, Wikipedia, 2021), (c) Playtica (US \$4.4 billion), acquired by a Chinese consortium in 2016 (Playtica, Wikipedia, 2021).

This shows the ability of Israel's tech firms to create highly innovative companies.

$$dlogW = 4.634dlogA - 0.420dlogTF. \tag{5.31}$$

$t\,25.15 - 6.09$

$R^2 = 0.9982\ DW = 1.95\ F = 21602\ N = 48$

$Period: 1973 - 2020\ Vector = 1 \Big/ d\left(d\left((TF_{-1})^2\right)\right)\ H = 0.039$

From 1973 to 2020 technological progress had very high effect on exports in Uganda. Equation (32) shows that within the given period a 1 percent increase in technological progress and total factor could have caused export growth to rise by 6.5 and −1.138 percent per annum respectively. The case of South Korea, Chau (2001) shows that the rapid economic growth of Korea resulted from the promotion of merchandise exports. Korea used cheap labor and low wages to establish its export oriented light industry. Meanwhile, when labor became more expensive relative to other developing countries, Korea's industrial composition shifted to heavy and chemical industries in 1970s. After mid−1980s when those industries started to become competitive in world market, Korea began to upgrade their technology to produce and develop sophisticated high−tech products (Chau, 2001, p.140; Ustabas & Ersin, 2016).

$$dlogX = 6.501dlogA - 1.138dlogTF. \tag{5.32}$$

$t\,31.21 - 14.61$

$R^2 = 0.9977\ DW = 2.13\ F = 20228\ N = 48$

$Period: 1973 - 2020\ Vector = 1 \Big/ d\left(d\left((TF_{-1})^2\right)\right)\ H = 0.039$

Lastly, we develop a technology diffusion model out of the relationship between the gross domestic product (GDP) and per capita income. On testing the model, we find that a 1 percent increase in economic growth might have caused growth in (household consumption, investment spending, government spending, export and import) per capita as well population (technology diffusion) growth to rise by 0.661, 0.226, 0.120, 0.057, −0.077 and 1.269 percent annually respectively, between 1972 and 2020 in Uganda (see under Equation (5.33) for details). We conclude that during the given period technological progress in the country could have been influencing economic growth at a yearly rate of 1.269 as given in Equation (33) below. For that matter we assume that the spread of technological progress within the technology society is proportional to the population growth rate. Therefore, it can be discerned from the technology diffusion rate that the diffusion rate is equal to the technology progress (1%) plus the population growth rate factor (0.2681) on average during the given period. Our finding may be justified because "there is a wide consensus that advances in technology are a key source of economic growth over the long term. Many of these advances, result, …., from purposeful investments in research and development (R&D)" (Comin & Mestieri, 2014, p.565).

$$\begin{aligned} d\log A &= 0.661\mathrm{dlog}\frac{C_n}{P_o} + 0.226dlog\frac{I}{P_o} + 0.120dlog\frac{G}{P_o} \\ &+ 0.057\mathrm{dlog}\frac{X}{P_o} - 0.077dlog\frac{M}{P_o} + 1.269dlogPo. \end{aligned} \tag{5.33}$$

$t\,8.58\ 9.79\ 6.40\ 6.14 - 3.69\ 26.11$

$R^2 = 1.0000\ DW = 2.08\ 535812\ N = 48$

$Period: 1973 - 2020\ Vector = 1 \Big/ d\left(d\left((Y)^2\right)\right)\ H = 0.003$

6. Conclusion, policy implications and limitation of the study

6.1. Conclusion

Firstly, in the paper we use (a) the neoclassical production function, (b) the causality principle that if event B comes after event A, then event A must be the event B (Alani et al., 2022), and (c) a modified Rubi (2008) causality model and apply it in regressions. This method is useful in obtaining more accurate capital and labor coefficients. However, evolutionary and some endogenous economists criticize the neoclassical model of being unable to explain the influence of technological progress on economic growth because the neoclassical model treats technological as manna that has fallen from heaven. On the contrary, we empirically find that the neoclassical model is capable of explaining the effects of innovation, capital, labor, capital productivity and labor productivity, consumption, investment, government spending, exports and imports on technological progress.

Secondly, much of economic literature postulates that increase in labor productivity has positive influence on economic growth. However, our empirical findings show that in the long run, increase capital productivity as well as labor productivity cause declines in economic growth. Thirdly, some economists worry that technological progress is the major cause of joblessness. On the contrary, in our theoretical framework and empirical results, we find that in the long run technological progress as well as innovation boost labor generation, capital accumulation, labor productivity and capital productivity.

Lastly, we endogenize the actual technological progress in the typical neoclassical function to obtain a neoclassical model having increasing returns to scale; but Romer (1986, 1990a, b) fails to perform this task well enough. The new neoclassical model is useful in explaining the effects of technological progress on economic growth.

6.2. Policy implications

(a) Some developing countries are still lagging behind in technologies. Based on the present study with respect to its outcomes, empirical results show that the policy implications for investments in technology is the stimulation technological progress leading to:
   (i) Promotion of technological capability, continued expansion of investment in indigenous R&D, as well as expansion in capital accumulation, labor generation, innovation, government spending, exports and imported technology, firm profits, capital productivity, labor productivity, economic growth and poverty eradication.
   (ii) Improvement in communication facilities and increased adaptation and use of technology similar to those in advanced industrial countries for steering economic development.
   (iii) Fostering indigenous technology through research centers establishment in both the public and private sectors as well as industrial growth and development.
   (iv) Establishment of domestic R&D institutes, to bring together scientists and engineers to work on common problems with efficient utilization of research facilities.

(b) Considering the fact that Cobb–Douglas production function has its own limitations, we developed more accurate ways of estimating the capital and labor coefficients based on
   (i) the fact that growth in capital and labor equals growth in investment spending and household consumption respectively,
   (ii) borrowing a relevant and good model from Rubi (2008), and
   (iii) adopting the GLS regression analysis technique.

6.3. Limitation of the study

According to some critiques, *the major limitation of the study is that it remains at the standard neoclassical framework and does not try to bring the later developments in economic growth and progress of nations in the contemporary context, when economic growth and progress are conditioned by several other factors, other than labor and capital, alone as dealt by the authors*. To address this problem the study has made attempts to borrow the idea of transmission mechanism from the Keynesian model and integrate it to form one of the variants of the neoclassical model. Therefore, in the grafted model, technology becomes the major channel through which movements in consumption, investment, government expenditure, exports, imports, disposable income, income taxes, etc. could affect the movements in economic growth.

Conflict of interest

We confirm there is no conflict of interest.

Acknowledgement of funders

This research was not funded by any organization.

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