# The Augmented and Integrative Model of Economic Growth: Theoretical and Empirical evidence from USA


## Abstract

The current nexus between education and economic growth leads us to propose a hybrid and integrated theoretical model. The variables chosen for this research were human capital and labour, and their impact on unemployment and economic growth was considered. In the validation of the theoretical model, different equations were contemplated, and the ARDL co-integration technique for its estimation was chosen. This study emphasizes the importance of technological progress, physical capital and human capital; the latter is measured by educational training and its interactive effect on employment and unemployment in explaining the behaviour of economic growth in the US from 1981-2019. The results show different statistical significance in the short and long term. These results corroborate the premise that there are partial adjustments in the short term, particularly after an economic crisis. In the long term, economic growth is affected by the positive or negative magnitudes of the product elasticity for each of the drivers considered. In terms of policy implications, a combination of structural and demand-driven policies must be implemented to reduce unemployment, in particular, to halt protracted economic recessions.



**Keywords:** Economic Growth, Physical Capital, Human Capital, Technological Progress, Employment, Unemployment

**JELClassification: A10, A20, C01, C50, C51, C52, E24, F66, O34**


## 1. Introduction

Previous studies on economic growth, particularly in the 1980s in the US (United States), led to the idea that there is a strong link between the level of education and productivity. This phenomenon deserves further study today by modelling of the relationship between economic growth, employed and unemployed labour force, weighted by the distinct levels of education. In competitive economies, a skilled labour force is more likely to benefit the economy, not only in terms of their output but also their lack of necessity for social entitlement and welfare. The results from an analysis can contribute to the literature by providing empirical evidence of the value of investing in formal and vocational education. A more highly educated population is in a better position to integrate technology into the economy, an important driver of economic growth.

The introduction of the size of the employed population, considering the differentiation at the level of education in empirical studies on economic growth in particular in the United States, as demonstrated by most of the studies previously reviewed in this study, lead us to consider the phenomenon that deserves to be analysed and evaluated today. Despite the interest, from the theoretical point of view has been observed appreciably, from the 80s of the last century, the modelling of the relationship between economic growth, employed and unemployed labour force, weighted by the distinct levels of education. On the other hand, their appearance or, more specifically, the results obtained from them, on the one hand, contributed to the transition of interest, by the economic literature, in studying the impact of education. Thus, technological progress can be an important driver to explicate the economic growth behaviour.

In historical and predictive terms, the GDP (Gross Domestic Product) in the US, measured in billions of dollars, rose between 1981-2019. This rising trend of output was briefly interrupted in 2009 due to the 2008 financial crisis. In turn, Gross Fixed Capital Formation in billions of dollars also experienced a fall in 2009, which is assumed to have occurred due to the 2008 financial crisis. At the same time, the labour force, measured in thousands of people, presented an upward trajectory. This increase in the labour force in the USA between 1981 and 2000 was primarily due to the entry of women into the labour market. Following that, the US experience a positive population growth between 2000 and 2019. Two interesting trends emerged in the 1990s related to education at secondary and higher education levels in the US. In 1991/1992, a sharp drop was observed in the percentage of adults aged 25 and 64 with a completed secondary education. After this time, the downward trend continued indicating that more people were leaving secondary education early. On the other hand, in 1992/1993, there was a sharp increase in the percentage of adults aged 25 to 64 with higher education, suggesting that more students decided to continue their education after finishing school.

In line with this context, it can be said that the level of Education, related to secondary education, in % of the population between 25 and 64 years, showed a sharp drop around the years 1991/1992 and with a decreasing trend from this period, suggesting that the percentage of adults, between 25 and 64 years old, with secondary education, has been decreasing, that is, suggests that the number of students, in this time horizon, who left school, studies before obtaining secondary education was increasing. In turn, the level of education related to higher education, in % of the population between 25 and 64 years, has a sharp increase around the years 1992/1993 with an increasing trend since then, suggesting that the percentage of adults, between 25 and 64 years, with higher education, has been increasing, that is, in this time horizon, more students have chosen to continue studying after finishing high school.

When the US labour market is further examined, the true impact of the 2008 financial crisis emerges. A secondary or higher education was no protection from unemployment from 2008 to 2010. During that period, the unemployment rate for those aged between 25 and 64 reached historic levels, and it would appear people with secondary education and people with higher education were equally affected.  From 2011 onwards, conditions in the labour market in the US improved along with the economic recovery, and until 2019 unemployment rates in general decreased.

With this previous context, it seems necessary to present some seismic considerations on the main approaches to theoretical modelling so that it is possible to base a proposal of formulations to explain the effect of the above-mentioned drivers on economic growth.

Theoretical studies considered in the literature present a coherent tool to analyze and evaluate the behaviour of economic growth and its drivers. Lucas' model (1988) differs from the model proposed by Romer (1990) in how knowledge is created and transmitted. This transmission occurs through human capital in the first model (Lucas, 1988), and spillover is related to the involvement of intelligent people. Lucas assumes that human capital rather than physical capital generates the non-rival and non-excludable scenario (Romer, 1990). Human capital is the skills, education, or talent of each individual, and it is clear that it is a rival commodity; that is more than one firm cannot use it simultaneously. As a counterweight to Romer's proposal that knowledge is a non-rival good (which will be explained later in this theoretical framework), from this assumption, the concept of spillover is made valid. Moreover, human capital seems to be correlated with population growth and the rate of savings, so the non-consideration of human capital can generate skewed estimates (Mankiw et al., 1992). Given this context, human capital and technological progress are pillars for growth and, therefore, economic development; however, it should be highlighted that each one acts in a particular way in economic activity. These two assumptions allow the deduction that the economic growth of a country converges to the steady state, or steady state of the per capita income, determined by a fixed production function with the technological factor being assumed as guaranteed, a given rate of savings and a constant depreciation, as referred in (Kasim, 2017), (Ogundari and Awokuse, 2018), (Matousek and Tzeremes, 2021), among others.

In this study, the integration of the Romer and Lucas models was proposed. As important drivers of economic growth in an economy, technological progress, human capital, and education structural components were included. These drivers are considered fundamental to increasing productivity, which will lead to economic growth, in addition to promoting job creation and individual and societal prosperity (Ogundari and Awokuse, 2018) maintain. It seems consensual that people with higher levels of training have more capacity to occupy decisive positions for economies, such as government leaders, decision-making positions in public entities, and national or foreign private companies, among other professions. In addition, according to the contributions of (Habibi and Amjad, 2020), human capital shapes the behaviour of society so that it presents a more formal and cordial economic, social and political environment, which acts as an attraction for domestic and foreign investment in a country. For a certain rate of accumulation of human capital, a higher level of savings or a lower rate of population growth tends to lead to higher income, and consequently, a higher level of human capital has greater impacts on income when human capital is taken into consideration (Mankiw et al., 1992).

Specifically, the objective of this paper is to shed light on the following questions: Can educational quality function as a proxy for higher education, which is essentially non-mandatory education? And if so, what are the channels through which educational quality operates? And how can educational quality affect the long-run income level?

It can be shown that in every period, the economy, as an aggregate, is entirely characterized by the aggregate output per worker and that how this variable evolves depends on the level of educational quality.

This research addresses the issue of incorporating the size of the employed population and differentiating it based on education levels in empirical investigations about economic growth, with a specific focus on the United States. The contribution of this article resides in its provision of empirical evidence and theoretical perspectives concerning the association between educational quality, economic growth, and individual income levels.

The paper is organized as follows. Section 2 presents the literature review. Section 3 analyzes the theoretical framework of economic growth models and proposes an augmented model considering the labour market and education quality in the US context. Section 4 describes the methodology and data. Section 5 examines the link between education and economic growth, discussing the results through technological progress measured by total patent applications (ideas) from workers and through the interactive effect between the level of education and employment and the level of education and unemployment. Section 6 states the conclusions.

## 2. Literature Review

The relationship linking economic growth and human capital has been widely investigated in recent decades. These studies have been theoretical and empirical and have analysed various economies and the impacts that human capital has on their economic activity. In this section, a brief literature review on the subject is given. Using a comprehensive sample of countries (100) and 35 years of observations, (Matousek and Tzeremes, 2021) proposed to explore the effect of human capital on economic expansion. Using a methodology for non-parametric and semiparametric analysis, they concluded that, in most cases, human capital contributes to economic growth is statistically significant. In addition, the outcome shows that the quality of human capital can be one of the factors that explain the difference in growth between countries (Matousek and Tzeremes, 2021). The positive impact of human capital on the economy was also observed by (Shidong et al., 2022) for the economies belonging to the G10. Going further, (Shidong et al., 2022), included the variable renewable energies in their analysis. This study demonstrated that human capital also positively affects this variable and that the impact of renewable energies and human capital, when used together, has a more significant impact on economic activity than when they are considered individually (Shidong et al., 2022). The BRICS countries (Brazil, Russia, India, China, and South Africa) were also investigated in this context. (Ganda, 2022)'s study sought to understand how human capital affects environmental quality and sustainability in these economies. The author concluded that human capital is significantly related to environmental quality and sustainability both in the short and long term (Ganda, 2022). The results found in (Zafar et al., 2019)'s research on the American economy converge with those found in (Shidong et al., 2022) and (Ganda, 2022). According to (Zafar et al., 2019), increased energy consumption and economic activity promote environmental degradation. However, human capital has an inverse relationship with the ecological footprint; that is, an increase in human capital contributes to environmental preservation. The results found by (Shidong et al., 2022), (Ganda, 2022), and (Zafar et al., 2019) are interesting since they provide evidence that human capital can be a key part of promoting sustainable growth. (Agasisti and Bertoletti, 2022) investigated human capital from a unique perspective; they studied the impact of regional higher education systems in 284 regions of the European continent for 18 years (2000-2017). They had as their objective to answer the following question “What is the impact of the characteristics of regional Higher Education Systems (HESs) on the economic growth of European regions?” The analysis indicated a beneficial effect among universities as well as an increase in local economies. In addition, the results show that a rise in the quality of research production has a clear positive effect on the GDP (Gross Domestic Product) per capita of the regions (Agasisti and Bertoletti, 2022). Taking into account the fundamental aspect that trade and human capital play in economic growth, (Majidi, 2017) studied these effects in Asian economies from 1990-2014. The results obtained through Ordinary Least Square (OLS) estimates indicated that foreign trade and human capital have a clear and significant impact on the economic improvement of Asia (Majidi, 2017). Also, on the Asian continent, (Fatimah et al., 2021) studied the effects of human capital and innovation capacity on the economic activity of Malaysia, Thailand, and Indonesia. The results showed that human capital positively affects the economy, while the capacity for innovation was not statistically significant (Fatimah et al., 2021). A similar effect of human capital was observed by (Fatimah et al., 2021), (Widarni and Bawono, 2021), and (Prasetyo and Kistanti, 2020) for the Indonesian economy. Also, in Asia (Maitra, 2016) investigated how investment in human capital and employment contributed to Singapore's economic growth in recent decades (1981-2010). It was observed that human capital and the labour force have a positive relationship with economic activity. In addition, human capital at first does not contribute to economic growth, unlike the labour force that immediately influences economic activity (Maitra, 2016). (Adeleye et al., 2022) studied the relationship between human capital and economic expansion in MENA

(Middle East and North African) member countries between 1980 and 2020. The results obtained contribute to the strengthening of the hypothesis that human capital is fundamental to economic growth (Adeleye et al., 2022). The relationships between physical, human capital, energy consumption, and its effect on GDP were investigated in Turkey by (Turna and Ceylan, 2022). With a NARDL (Nonlinear Autoregressive Distributed Lags) methodological approach, the effects were observed between 1965 and 2014. The results of the estimates indicated a relationship of asymmetry between physical capital and GDP in the short and long term, while energy consumption had a direct relationship with economic activity. In other words, increased consumption causes an increase in GDP, and the same relationship was observed for human capital (Turna and Ceylan, 2022).

The focus of research for this study, the American economy, has been the focus of several other studies. In this context, (Faggian et al., 2017) studied the human capital ratio in the United States between 2000 and 2007. They used a broader concept for the definition of human capital, including creativity, entrepreneurship, and education (Faggian et al., 2017). The results of the estimates indicate that of the three variables used for human capital, education has the greatest contribution to economic growth, thus concluding that the best strategies for economic development involve the retention of a highly educated labour force (Faggian et al., 2017). A similar relationship was observed in (Baldwin and Borrelli, 2008) and (Fan et al., 2016). The study proposed by (Jorgenson and Fraumeni, 1992), investigated the impact of investment in education in the American economy between 1948 and 1986. The results indicate that investment in human and non-human capital is responsible for an overwhelming proportion of American economic growth in the period studied (Jorgenson and Fraumeni, 1992). (Bowen and Qian, 2017) expanded the investigative range of human capital in the U.S. when they set out to study the impact of investment in higher education in the U.S. states. The results indicated that state spending on higher education does not promote an increase in economic activity, but an improvement in economic performance causes spending on higher education to increase, so it is concluded that higher education is a normal good (Bowen and Qian, 2017). In addition, the researchers concluded that investment in human capital promotes an improvement in economic activity (Bowen and Qian, 2017), a result that corroborates the findings of (Faggian et al., 2017) and (Jorgenson and Fraumeni, 1992). The results found by (Baldwin et al., 2011) indicate that state investment in education promotes an increase in state GDP (Baldwin et al., 2011). The state of Georgia was analysed in isolation between 2006 and 2008 by (Clarke et al., 2015). The analysis showed that municipalities in Georgia with low education tended to have difficulties in growing economically. However, the results also indicated that responding to the low quality of the workforce only with investment in education will not promote economic growth directly since the relationship between unemployment and the effect of poverty impedes local economic growth. Thus, the authors determined that economic growth is linked to a skilled and uneducated workforce (Clarke et al., 2015). A result different from that was obtained by (Baldwin et al., 2011). The sample used in their research was different, but this demonstrates that there is no total agreement in the academy on human capital and its effects.

Economic expansion and employment/unemployment are variables of paramount importance for the development and implementation of economic policies. According to the results found by (Altunöz, 2019), for the period 2000-2012, Okun's Law is valid for the Eurozone (Altunöz, 2019). A causal link between economic growth, Foreign Direct Investment (FDI), exports, and unemployment was found for the oldest members of the European Union (Dritsakis and Stamatiou, 2018). The results of the estimates of the model indicated three two-way causalities among economic improvement and exports, exports and foreign direct investment, and exports and unemployment. In addition, three one-way relationships were observed from the FDI for economic expansion, from foreign direct investment to unemployment and economic growth to unemployment (Dritsakis and Stamatiou, 2018). The relationship between unemployment and economic growth in Eastern Europe was investigated by (Okur et al., 2018) between 1992-2014 within the context of Okun's Law. The results of the estimates indicated that unemployment is positively affected by economic growth, according to the authors, and for this sample, a 1% increase in GDP caused a 0.8% drop in unemployment (Okur et al., 2018). For the Romanian economy, it was observed that investment promotes economic growth and implicitly is responsible for generating more jobs (Daniela et al., 2019). The existing relationship between unemployment and economic activity was investigated in Nigeria by (Ikechukwu, 2017) between 1970-2014. Applying the ARDL (Autoregressive Distributed Lagged) methodology, the authors validated Okun's Law for Nigeria, meaning there is a negative relationship between unemployment and economic expansion (Ikechukwu, 2017). Still, in Africa, to be more precise, South Africa (Pasara and Garidzirai, 2020) set out to investigate the relationship between economic growth, unemployment, and gross capital formation. The result of the first model showed a long-term and positive link between economic growth and gross capital formation, while unemployment did not affect economic activity in the short term. The second model proposed showed a positive relationship between unemployment and gross capital formation, and the third and final model observed a reverse relationship between unemployment and economic expansion (Pasara and Garidzirai, 2020). (Sharma and Sharma, 2019)’s goal in studying the economies of China and India was to understand how economic growth affects job creation. The results indicated that economic growth did not have much impact on the generation of new jobs in these economies for the period surveyed (1985-2017) (Sharma and Sharma, 2019). In contrast, Taiwan (Chen, 2016) researched entrepreneurship, economic growth, and employment. The results pointed to real GDP growth increasing job vacancies, but the reverse was not observed; that is, an increase in the number of jobs will not necessarily be reversed in real GDP growth. Conversely, entrepreneurship contributes positively to job creation and GDP (Chen, 2016). In Jordan, there was an adverse relationship between unemployment and the economy but a positive relationship ship between education, the female population, the urban population, and unemployment (Hjazeen et al., 2021).

## 3. Methodology and Data

### 3.1. Theoretical Framework

It is well known that in 1956 Solow proposed a neoclassical economic growth model, which considered only three factors that promote economic growth: physical capital $K_{(t)}$, workforce $L_{(t)}$, and knowledge $A_{(t)}$, thus having the following output function $Y_{(t)}$.

$$Y_{(t)} = F[K_t, L_t, A_t] \quad (1)$$

Which, $K_{(t)}$ represents durable production goods, such as machinery, for example. $L_{(t)}$ represents the aggregate that the human workforce contributes to economic growth, which varies in time depending on the population growth rate. Finally, $A_{(t)}$ knowledge, is also called technology (Barro and Sala-i-Martin, 2000).

However, this model proved unsatisfactory in explaining growth in the long term because, according to (Barro and Sala-i-Martin, 2000), when considering constant technological progress, the economy would reach a steady state, and any change in the variables would not promote a change in the state of the economy. When considering constant knowledge ($A$,) naturally, over time, the economy would show decreasing return on capital, which would discourage new investments and not promote economic growth. To explain long-term growth, the $AK$ model was developed, already being an adapted form of the model proposed by Solow. The main feature of this model is the absence of decreasing capital return (Barro and Sala-i-Martin, 2000). Here is the following $AK$ function: $Y = AK$

Where $A$ is a positive constant that represents the technological level. Moreover, the $K$ has a broader sense of incorporating human capital. Therefore, in this model, the return on capital will always be constant when $A > 0$ (Barro and Sala-i-Martin, 2000). In the AK model, long-term and short-term economic growth is given by the same equation. In this model, changes in the parameters can affect the levels and growth rates of variables (Barro and Sala-i-Martin, 2000). As technological progress may vary, a technological improvement, A, tends to raise the marginal and average products of capital, which increases the rate of economic growth and alters the savings rate (Barro and Sala-i-Martin, 2000). In this way, it should be highlighted that technology ($A_{(t)}$,) can be improved over time and the technological level may be different between countries (Barro and Sala-i-Martin, 2000), which would in a way explain the difference between economies as well. Therefore, technological ($A_{(t)}$,) progress was a way process by which the economy could escape the return of decreasing capital in the long run (Barro and Sala-i-Martin, 2000).

Solow-Swan (1956) proposed a simplified growth model, which considers only the three variables. The model is represented by the following equation.

$$Y = A \times L^{(1-\alpha)} \times K^{\alpha} \, (2)$$

All the variables that make up the model are considered endogenous, so the model was received as an endogenous growth model. The variables physical capital $(K)$ and labour $(L)$ contribute to economic growth $(Y)$ at a decreasing rate, while technology $(A)$ is considered constant (Kasim, 2017). However, technological progress in the form of innovation was the only way an economy could escape the decline in returns in the long run (Barro and Sala-i-Martin, 2000). The variables that represent human capital and labour have two representations: $HE_{at}$ and $L_{at}$ which represent the level of adult education (secondary education) for the population between 25 and 64 years and the employment rate for adults with secondary education between 25 to 64 years, respectively. While $HE_{bt}$ and $L_{bt}$ stand for the level of adult education (higher education) for the same age spam and the employment for the adults with higher education, respectively. In the second half of the twentieth century, more specifically in 1962, Arthur Okun announced, using quarterly data from 1947 and 1960, an empirical pattern, which was based on a negative relationship between cyclical unemployment and cyclical real output (Okun, 1962). However, this result is not a consensus among researchers on the subject of this theme. According to (Nagel, 2015), some articles confirm the negative short-term relationship between the variables, while others deny this existence, even questioning whether it is a law. In the current context, an effort is made to understand whether unemployment is an output-dependent variable or whether there is a mutual dependence between variables (Nagel, 2015). In addition, there are theoretical currents that believe that technological progress can influence the direction of the unemployment rate (Nagel, 2015). Finally, (Nagel, 2015) in his article, observed several relationships between economic growth and unemployment, which were the effect of creation (negative correlation between the variables unemployment and economic growth), the effect of creative destruction (positive correlation), the pool of savings effect (negative correlation) and failure effect (negative correlation). Having exposed this, what relationship will be observed between the variables of economic growth and unemployment? In addition, in what kind of professions does technology affect the level of unemployment?

Being a variable of paramount importance for economic growth, as demonstrated in the models above, technological progress $(A_t)$ was taken into account in the model proposed in this research, making it an endogenous economic growth model that is based on the model proposed by (Castelló-Climent and Hidalgo-Cabrillana, 2012). In the model proposed by (Castelló-Climent and Hidalgo-Cabrillana, 2012), economic growth is the result of physical and human capital within a context in which educational quality is an exogenous factor (Castelló-Climent and Hidalgo-Cabrillana, 2012). In this model, individuals must attend primary education, but to achieve a higher educational level, they must use their resources (Castelló-Climent and Hidalgo-Cabrillana, 2012). The authors assume that individuals live for two periods. The first is fully dedicated to acquiring knowledge, in other words, the accumulation of human capital. In the second period, agents offer their units of human capital (Castelló-Climent and Hidalgo-Cabrillana, 2012). In this way, the production function of this model, considering technological progress is:

$$Y_t = A_t\, K_t^{\alpha} H_t^{1-\alpha} = A_t\, H_t K_t^{\alpha} \quad (3)$$

The economic agents are inserted in a perfectly competitive environment. Due to this circumstance, in a given period, producers may choose the amount used of human capital $(H_t)$ and physical capital $(K_t)$. Therefore, the inverse demand function of the production factors is given by:

$$r_t = f'(K_t) = \alpha K_t^{\alpha-1},$$
$$W_t = f(K_t) - f'(K_t)K_t = (1-\alpha)K_t^{\alpha} \quad (4)$$

Which, $r_t$ represents the rate of return on capital and $W_t$ is the wage rate per efficiency unit of labour (Castelló-Climent and Hidalgo-Cabrillana, 2012). To simplify, the depreciation of the total capital is considered, i.e.$\delta = 1$, therefore, $R_{t+1} = 1 + r_{t+1} - \delta = r_{t+1}$ (Castelló-Climent and Hidalgo-Cabrillana, 2012). In this way, the capital stock in $t+1$ comes from savings. For a better understanding of the model, see (Castelló-Climent and Hidalgo-Cabrillana, 2012), where the authors develop mathematically, and explain in detail, the function of individuals, the production function, the formation of human capital, and investment decisions and subsequently apply these to achieve the overall balance of the proposed model. The authors consider the quality of education low $(\tilde{\theta}_{t,a_H})$ and consider that all individuals must have primary education and that the stock of capital in $t+1$, therefore, $K_{t+1} = B_t = \beta Y_t$ (Castelló-Climent and Hidalgo-Cabrillana, 2012). The formation of human capital begins with decision-making; individuals need to decide whether they will invest in higher education, so they need to decide how much of their gains will be allocated, in this way, the variable $I_t$. Having exposed this, there is the following production function for higher education $h_{t+1,a_j}^{high} = a_j\theta(\mu + \theta I_t)^{\varepsilon}$, with $j = H, L$ and, $\varepsilon < 1$ (Castelló-Climent and Hidalgo-Cabrillana, 2012). The functions make it clear that the production function of human capital depends on the quality of education $(\theta)$ and the ability of the individual ($a_j$). If $I_t = 0$, the individual had only primary education, so his production function is $h^{pri}_{t+1,a_j} = a_j\theta\mu^{\varepsilon}$, in which $\mu$ is an exogenous variable, that is, the value spent by the government in education (Castelló-Climent and Hidalgo-Cabrillana, 2012). Individuals with more talent are expected to have greater total and marginal returns when they choose to invest in higher education than less talented individuals. The quality of education tends to vary according to the level of development of this locality (Castelló-Climent and Hidalgo-Cabrillana, 2012). Considering in aggregate the two categories of human capital, individuals with primary education and individuals with high education, the aggregate function of human capital is $H_{t+1} = \gamma\theta a_L\mu^{\varepsilon} + (1-\gamma)\theta a_H(\mu + \theta I^*_{t,a_H})^{\varepsilon}$.

Demonstrating the production function of human capital, it is possible to find the ratio between labour capital, according to the following equation, $K_{t+1} = \frac{\beta Y_t}{\theta\bar{a}\mu^{\varepsilon}} = K^I(Y_t,\theta)$, where $\bar{a} = \gamma a_L + (1-\gamma)a_H$ is the average ability (Castelló-Climent and Hidalgo-Cabrillana, 2012). When considering only individuals with high education, there is the following aggregate of physical capital, $K_{t+1} = \beta Y_t - \gamma I^*_{t,a_H}$ . Thus, there is the following capital-labour ratio:

$$K_{t+1} = \frac{\beta Y_t - \gamma I^*_{t,a_H}}{\gamma\theta a_L\mu^{\varepsilon} + (1-\gamma)\theta a_H(\mu + \theta I^*_{t,a_H})^{\varepsilon}} \quad (5)$$

Therefore, the per capita product of the economy proposed in this economic model is given by:

$$Y_{t+1} = (\beta Y_t - (1-\gamma)\gamma I^*_{t,a_H})^{\alpha} x \, (\gamma\theta a_L\mu^{\varepsilon} + (1-\gamma)\theta a_H(\mu + \theta I^*_{t,a_H})^{\varepsilon})^{1-\alpha} (6)$$

In another model, Mankiw, Romer, and Weil (Kasim, 2017) developed the Solow model by considering human capital ($HE$), as a factor of the cumulative effect of education at the secondary level. In this way, the cumulative effect of education that a worker has received was added to the model and became a multiplier of labour to signal that education is a factor that contributed to the increase in economic growth. Thus, two separate equations for the augmented model initiated by Mankiw, Romer, and Weil (Kasim, 2017) were proposed. Using both equations, the following equations are considered.

$$Y_t = A_t \, K_t^{\alpha_t} \; [HE_{at} * L_{at}]^{(1-\alpha_t-\beta_t)} \quad (7_a)$$

$$Y_t = A_t \, K_t^{\alpha_t} \; [HE_{bt} * L_{bt}]^{(1-\alpha_t-\beta_t)} \quad (7_b)$$

In this approach, human capital ($HE_{at}$ and $HE_{bt}$) was added to the model and became a multiplier of employment to signal that a multiplier effect between employment and level of education is another factor that contributes to the decreasing effect in economic growth.

$$Y_t = A_t \, K_t^{\alpha_t} \, [HE_{at} * U_{at}]^{(1-\alpha_t-\lambda_t)} \qquad (8_a)$$

$$Y_t = A_t \;\; K_t^{\alpha_t} [HE_{bt} * U_{bt}]^{(1-\alpha_t-\lambda_t)} \qquad (8_b)$$

In the equations $8_a$ and $8_b$, a new variable was presented, unemployment $U_{at}$ and $U_{bt}$. $U_{at}$ denotes for unemployment level for the population between 25 and 64 years with secondary education, while $U_{bt}$ stands for the unemployment level for the population with higher education in the same age span.

Next, there are equations $9_a$ and $9_b$, which are the integration of the models. Equation $9_a$ is the result of the integration of equations $7_a$ and $8_a$, while $9_b$ is the junction of equations $7_b$ and $8_b$.

$$Y_t = A_t \, [HE_{at} * L_{at}]^{(1-\alpha_t-\beta_t)} * [HE_{at} * U_{at}]^{(1-\alpha_t-\lambda_t)} \times K_t^{\alpha_t} \quad (9_a)$$

$$Y_t = A_t \, [HE_{bt} * L_{bt}]^{(1-\alpha_t-\beta_t)} * [HE_{bt} * U_{bt}]^{(1-\alpha_t-\lambda_t)} \times K_t^{\alpha_t} \quad (9_b)$$

However, the model estimated in this work is in logarithmic form, and all equations numbered by equation $9_a$ to $equation\, 11_b$ are presented in logarithmic form, where $Y_t$ is the Gross Domestic Product (GDP) and dependent variable. $A_t$ is the Technological Progress measured by Total Patents (Ideas) per worker, $K_t$ is the Gross Fixed Capital Formation (GFCF), $HE_{at}$ level of adult education (secondary education) for the population between 25 and 64 years. $HE_{bt}$ is the level of adult education (Tertiary education) for the same age; $U_{at}$ denotes the unemployment level for the population between 25 and 64 years with secondary education. $U_{bt}$ represent the unemployment rate for adults with Tertiary education in the same age represents. $L_{at}$ is the employment rate for adults with secondary education between 25 to 64 years, and $L_{bt}$ denotes the employment rate for adults with Tertiary education in the same age interval.

## 4. Methodology and data

### 4.1. Testing for Stationarity: Unit Root Test with Structural Breaks

To estimate a more robust and dependable ARDL model so that it meets the normality condition of the ARDL, every variable needs to be integrated into I (1) or I (0), and no variable can be integrated into I (2). The entire approach of the Autoregressive-Distributed Lag model is based on the assumption that the analysed variables are of order one or zero. That said, the analysis of the unitary root gives a better understanding of the order of integration of the variables studied.

The test suggested by Zivot and Andrews in (Zivot and Andrews, 1992) uses as a basis the unit root test developed by Perron but differs in the way it deals with a structural breakdown. Perron deals with this in an exogenous manner, while Zivot and Andrews treat structural breaks as endogenous factors (Zivot and Andrews, 1992). According to (Narayan, 2005), the null hypothesis of the data set is a unified process without a structural break, while the alternative hypothesis is a static tendency with a structural break in the trend behaviour that occurs in an unknown period (Narayan, 2005). The stationary test proposed by (Clemente et al., 1998) considers the possibility of two changes in the mean, a detrended structural break and a unit root test (Moutinho et al., 2020).

(Zivot and Andrews, 1992) introduced three models for performing unit root testing with an endogenous structural break. The test comprises three distinct strands, denoted as (10), (11), and (12). Each equation corresponds to a different scenario, indicating a potential break in the intercept, trend, or both intercept and trend, respectively.

$$\Delta z_t = \vartheta_1 + \vartheta_2 t + \xi z_{t-1} + \psi DU_t + \sum_{i=0}^{r} \omega_i \Delta z_{t-i} + \varepsilon_t \ (10)$$

$$\Delta z_t = \vartheta_1 + \vartheta_2 t + \xi z_{t-1} + \delta DT_t + \sum_{i=0}^{r} \omega_i \Delta z_{t-i} + \varepsilon_t \ (11)$$

$$\Delta z_t = \vartheta_1 + \vartheta_2 t + \xi z_{t-1} + \psi DU_t + \emptyset DT_t + \sum_{i=0}^{r} \omega_i \Delta z_{t-i} + \varepsilon_t \ (12)$$

In order to investigate the presence of multiple structural breakpoints, Clemente, Montañés and Reyes unit-root test with double mean shifts, proposed by (Clemente et al., 1998) and a test for multiple breaks at unknown breakpoints, developed by (Ditzen et al., 2021) tests are employed in this study.

The test proposed by (Clemente et al., 1998) expands upon the methodology introduced by Perron and Vogelsang (1992) by examining scenarios involving two mean changes. The null hypothesis $(H_0)$ and proposed alternative $(H_1)$ are respectively, $H_0: y_t = y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + u_t$ and $H_1: y_t = \mu + d_1 DU_{1t} + d_2 DTB_{2t} + e_t$. $DTB_{it}$ is a pulse variable that assume the value 1if $t = TB_i + 1$ $(i = 1,2)$ and assume 0 if not, $DU_{it} = 1$ if $t > TB_i$ $(i = 1,2)$ and 0 if not. Finally, $TB_i$ stands for the periods where the mean are modified (Clemente et al., 1998). The test examines the possibility of two structural breaks by employing the following equation:

$$y_t = \mu + \rho y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + d_1 DU_{1t} + d_2 DU_{2t} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \ (13)$$

Lee and Strazicich, (2003) present an innovative endogenous two-break Lagrange multiplier unit root test that is capable of accommodating breaks in both the null and alternative hypotheses. The teste can be estimate through the equation $\Delta y_t = \delta' \Delta Z_t + \Phi \bar{S}_{t-1} + u_t$, in which, $\bar{S}_t = y_t - \tilde{\psi}_x - Z_t \tilde{\delta}, t = 2, \ldots, T$, $\hat{\delta}$ is the coefficient of the regression $\Delta y_t$ in $\Delta Z_t$. The null hypothesis $(H_0)$ is given by $\Phi = 0$. The rejection of the null hypothesis leads to a clear indication of trend stationarity (Lee and Strazicich, 2003).

The test introduced by (Ditzen et al., 2021) considers the significance of examining multiple structural changes in scenarios where there are no trending regressors. The test has the ability to detect and determine the timing of an unknown number of structural breaks, using the statistic proposed by (Bai and Perron, 1998).

### 4.2. The Autoregressive-Distributed Lag (ARDL) Approach

To estimate the results of this study, the Autoregressive-Distributed Lag (ARDL) methodology was applied. Developed by (Pesaran et al., 2001), for the examination of the long-run relationship among the variables within a Vector Autoregression (VAR) framework. This methodology can be used independently if the regressors are unified in order one ($I(1)$) or zero order ($I(0)$), therefore stationary (Moutinho et al., 2020). The ARDL approach has advantages over other methodologies that can be applied, for example the (Søren, 1991) technique. The major advantage is that the limit check is suitable regardless of whether the rebuttals contained are essentially $I(0)$, $I(1)$, or commonly co-integrated (Narayan and Narayan, 2005). So, the bound analysis does not rely on pre-checking the structure of integration of the variables; this reduces uncertainty related to pre-verification of the order of integration (Narayan and Narayan, 2005). Another advantage is the Unrestricted Error Correction Model (UECM). The ARDL equation can be written as follow:

$$\Omega(L,p)y_t = \alpha_0 + \sum_{i=1}^{k} \beta_i(L,q_i)x_{it} + \delta'^{w_t} + \mu_t \quad (14)$$

Where:

$$\Omega(L,p) = 1 - \Omega_1\delta_1 L^1 - \Omega_2\delta_2 L^2 - \cdots \Omega_p L^p, \quad (15)$$

$$\beta_i(L,q_i) = \beta_{i0} + \beta_{i1}L + \beta_{i2}L^2 + \cdots \beta_{iqi}L^{iqi}, i = 1, 2, \ldots, k, \quad (16)$$

$y_t$ is the variable explained; $\alpha_0$ intercept specification; $L$ is a lag operator such as $Ly_t = y_{t-1}$, and finally, $w_t$ is an $s\ x\ 1$ vector of deterministic variables (Narayan and Narayan, 2005).

The initial step in the procedure for testing limits involves the estimation of all Autoregressive Distributed Lag (ARDL) equations using the Ordinary Least Squares (OLS) method. This estimation is conducted to examine the presence of a long-run relationship among the variables under investigation. (Pesaran et al., 2001) propose a limits test based on the F distribution, which serves as an asymptotic distribution for assessing the joint significance of coefficients in their levels along with a time lag, relative to critical values established by (Pesaran et al., 2001). It is important to note that the calculation of limits in ARDL tests is sensitive to the selection of the lag length, and an inappropriate choice can lead to biased results. To determine the optimal lag length, criteria such as Akaike Information Criterion (AIC), Schwarz Bayesian Criterion (SBC), and Hannan-Quinn Criterion (HQC) are employed to find the most suitable lag length.

The co-integration test is fundamental because, according to (Jordan and Philips, 2018), a time series can carry with it a kind of memory so that the current conclusions are the result of all previous stochastic shocks, in addition to the possibility of some innovation. This type of series tends to be integrated into order 0 or *I* (1), a nonstationary form. However, this type of series should not be included in traditional regression models since this type of data is more prone to statistically significant relationships simply due to random chance (Jordan and Philips, 2018). Nevertheless, one or more series may have short- and long-term *I* (1) relationships. In other words, while short-term disturbances can fend off series over time, this trend can be corrected, and the series establish a long-term relationship. This is called the co-integrated series (Jordan and Philips, 2018). As described above, not every relationship between *I* (1) is co-integrated, so it is necessary to test for co-integration. The co-integration test is performed by using a hypothesis test, in which the null hypothesis ($H_0: \theta_1 = \theta_2 = \cdots = \theta_n$ ) is opposed to the alternative ($H_1: \theta_1 \neq \theta_2 \neq \cdots \neq \theta_n$ ), applying the F-test.

The F-test does not have a normal distribution. The direction to which it leans depends on whether; (i) the variables of the Autoregressive-Distributed Lag model are order zero or one; (ii) the number of regressors; and (iii) if the ARDL model has, on the one hand, an intercept, or on the other hand, or simultaneously, has a direction (Narayan and Narayan, 2005). If F-statistic values are outside critical limits, a decision can be made even if the order of integration of regressors is not acknowledged (Narayan and Narayan, 2005), in other words, variables are integrated assuming that the null hypothesis of no co-integration is not accepted. Alternatively, it can accepted that the variables are not co-integrated. Having ensured non-stationarity and co-integration among the variables, it is conceivable to assume which divergence of the long-term balance of the variables influences the short term. The explanation for these divergences can be expressed by the error correction representation of the ARDL can be written as follow:

$$\Delta y_t = \alpha_0 + \theta_0 y_{t-1} + \theta_1 x_{1,t-1} + \cdots + \theta_k x_{k,t-1} + \sum_{i=1}^{p} \alpha_i \Delta y_{t-1} + \sum_{i=0}^{q_1} \beta_1 \Delta x_{1,t-j} + \cdots + \sum_{j=0}^{qk} \beta_{1j} \Delta x_{k,t-j} + \epsilon_t \quad (17)$$

With the $t-1$ value appearing in levels, the values of all returns in $t-1$ appear in levels and until the lag of the first difference of the explained variable ($p$) and the regressors ($q_k$) (Jordan and Philips, 2018).

$\sigma_i = 1 - \sum_{j=1}^{p} \emptyset_{i,k}$, means the speed of adjustment of the coefficients, the speed of adjustment measures how quickly a deviation is corrected, and the long run coefficients are given by $\theta = \frac{\sum_{j=0}^{q} \beta_{i,k}}{\alpha_i}$, The equilibrium ratio of the independent variables on the dependent variable is given by $\theta_i$ (Moutinho et al., 2020).

The standard co-integration tests are ineffective in establishing a co-integrating relationship among variables when structural breaks are present. To overcome this challenge, researchers such as (Gregory and Hansen, 1996) and (Maki, 2012) developed a co-integration approach that incorporates the possibility of structural breaks in the co-integrating vectors. This alternative methodology enables the detection of co-integrating relationships accurately even in the presence of structural breaks.

### 4.3. Data

In this study, the following variables were used: Gross Domestic Product (GDP) in billions of dollars (at constant prices in 2010), denoted as $Y_t$, Patent technology as a percentage of the Total Patents Applications by workers, more specifically a proxy measured by the ratio between Total Patents (the number of patents applications by residents and non-residents) and Labour Force, Gross Fixed Capital Formation (FBKF) in billions of dollars (at constant prices in 2010) denoted as $K_t$. The Level of Education, in this case, referring to Secondary Education, is a percentage of the population aged between 25 and 64 years, denoted as $HE_{at}$. The Level of Education, in this case, refers to Tertiary Education as a percentage of the population aged between 25 and 64 years, denoted $HE_{abt}$. Unemployment, in this case as a percentage of the population aged 25-64 with secondary education, is denoted as $U_{at}$. Unemployment, in this case for Tertiary Education, as a percentage of the population aged between 25 and 64 years, denoted as $U_{bt}$, Employment, in this case for secondary education, as a percentage of the population aged between 25 and 64 years, denoted as $L_{at}$, and Employment, in this case referring to Tertiary Education, as a percentage of the population aged between 25 and 64 years, denoted as $L_{bt}$. According to data access sources, as variables, GDP and FBCP were collected from the World Development Indicators database. All other variables were collected from the Organization for Economic Co-operation and Development (OECD) database. The variables relate to the United States of America and are related to the period from 1981 to 2019 (39 observations).

## 5. Results and Discussion

### 5.1 Results of unit root tests

To confirm the stationarity, tests were performed for all variables: Economic Growth (GDP), Patents Application (the number of patents applications by residents and non-residents) per Worker, Gross Fixed Capital Formation, the interaction between Secondary Education and Employment with Secondary Education, the interaction between Tertiary Education and Employment with Tertiary Education, the interaction between Secondary Education and Unemployment with Secondary Education, and the interaction between Tertiary Education and

Unemployment with Tertiary Education.. From the results of the Zivot and Andrew's break Unit root test (see Table 1), the results of the Strazicichi´s break (Table 2) and Multiple breaks shown by Ditzen et al. (2021) in Table 3, it was observed that all variables showed a stationary state either in the first difference under trend and an intercept case with a 1% and 5% significance respectively; that is, they follow an integrated process of order 1. All variables considered except the variable of Economic Growth (GDP) rate are not stationary in level, but stationary in first difference, considering the trend. When considering the intercept and the variables Total Patents (the number of patents applications by residents and non-residents) per Worker and the interaction between Secondary Education and Employment with Secondary Education, they are not stationary in, but stationary in first difference.

**Table 1 -** Zivot and Andrews (1992) Structural Break Unit Root Test Considering the Trend and Intercept

| Variables | Trend | | | | Intercept | | | |
|---|---|---|---|---|---|---|---|---|
| | At level | | At 1st difference | | At level | | At 1st difference | |
| | Minimum t-statistic | Time-Break | Minimum t-statistic | Time-Break | Minimum t-statistic | Time-Break | Minimum t-statistic | Time-Break |
| Economic Growth (GDP) | -4.472** | 2005 | -5.879*** | 2010 | -4.949** | 2008 | -5.811*** | 2012 |
| Patents Application (Ideas) per Worker | -3.75 | 2013 | -6.419*** | 2000 | -3.453 | 1998 | -6.209*** | 1997 |
| Gross Fixed Capital Formation | -3.742 | 2004 | -4.289** | 2010 | -4.956** | 2008 | -4.486** | 2011 |
| Secondary Education x Employment with Secondary Education | -3.28 | 1987 | -6.068*** | 1993 | -2.798 | 2011 | -6.555*** | 1992 |
| Tertiary Education x Employment with Higher Education | -3.505 | 1997 | -6.452*** | 1993 | -10.099*** | 1992 | -7.002*** | 1992 |
| Secondary Education x Unemployment with Secondary Education | -3.558 | 2013 | -4.655** | 2010 | -5.248** | 2011 | -5.248** | 2011 |
| Tertiary Education x Unemployment with Tertiary Education | -3.928 | 2013 | -4.846** | 2010 | -5.255** | 2011 | -5.255** | 2011 |

Note: the level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and 10% by *. The critical value in a test with trend at 1% is – 4.93, at 5% is - 4.80 and at 10% is - 4.42; while test estimation with an intercept at 1% is – 5.34, at 5% is – 4.80 and 10% is - 4.58, respectively. The maximum lag order is 4 in both unit root tests

According to the different structural break unit root tests, some different breaks in the time periods are revealed, according to the test of structural unit root employed. However, with the following series of variables, Economic Growth (GDP), Total Patents (the number of patents applications by residents and non-residents) per Worker, Gross Fixed Capital Formation, the interaction between Secondary Education and Unemployment with Secondary Education, and the interaction between Tertiary Education and Unemployment with Tertiary Education, a trend at first difference shows a mixed optimal structural breakpoint in the analysis.

**Table 2** - Lee-Strazicich (2013) Unit Root Test for the Variables

| Variables | S {1} | Constant | D | DT | D | DT |
|---|---|---|---|---|---|---|
| Economic Growth (GDP) | | | | | | |
| Coefficient | -0.4945 | 0.0176 | 0.0075 | 0.0157 | -0.0072 | -0.0275 |
| T-Stat | -3.2422 | 1.8219 | 0.4911 | 1.486 | -0.4521 | -3.8414 |
| Break Year | - | - | 1984 | 1984 | 2007 | 2007 |
| Patents Application per Worker | -0.7087 | -436.8157 | 1155.8762 | 1776.8191 | 1778.2373 | -719.345 |
| T-Stat | -4.1908 | -1.2726 | 1.3119 | 4.8261 | 1.9545 | -1.679 |
| Break Year | - | - | 1999 | 1999 | 2012 | 2012 |
| Gross Fixed Capital Formation | -0.3785 | 0.033 | 0.0067 | 0.0296 | -0.1753 | -0.0211 |
| T-Stat | -2.7332 | 3.4894 | 0.1696 | 1.5341 | -4.6191 | -1.1292 |
| Break Year | - | - | 1996 | 1996 | 2008 | 2008 |
| Secondary Education x Employment with Secondary Education | -0.5345 | 0.0093 | 0.167 | -0.2268 | 0.0672 | 0.1308 |
| T-Stat | -3.4164 | 0.2934 | 1.622 | -4.2247 | 0.7316 | 2.6733 |
| Break Year | - | - | 1990 | 1990 | 1997 | 1997 |
| Tertiary Education x Employment with Higher Education | -0.77 | 0.1767 | -0.6783 | 0.4939 | 0.1514 | -0.646 |
| T-Stat | -4.4756 | 4.4977 | -4.9558 | 6.0098 | 1.3474 | -7.1351 |
| Break Year | - | - | 1990 | 1990 | 1994 | 1994 |
| Secondary Education x Unemployment with Secondary Education | -0.5386 | 4.7028 | -0.4654 | -6.0178 | 18.5632 | 0.0677 |
| T-Stat | -3.4343 | 2.1817 | -0.1368 | -2.4833 | 5.3201 | 0.0482 |
| Break Year | - | - | 1984 | 1984 | 2008 | 2008 |
| Tertiary Education x Unemployment with Tertiary Education | -0.573 | 1 | -3.9934 | 4.1709 | 0.9545 | -7.1356 |
| T-Stat | -3.5845 | 2.3303 | -1.9286 | 3.8105 | 0.5154 | -5.0731 |
| Break Year | - | - | 2007 | 2007 | 2011 | 2011 |

Note: The critical value range of 1% is -7.196 to -6.691. The critical value range of 5% is -6.312 to -6.108. The critical value range of 10% is -5.998 to -5.779.

**Table 3 -** Sequential Test for Multiple Breaks at Unknown Breakpoints Ditzen et al. (2021) for the Variables

| | GDP | Patents Application per Worker | Gross Fixed Capital Formation | Secondary Education x Employment with Secondary Education | Tertiary Education x Employment with Higher Education | Secondary Education x Unemployment with Secondary Education | Tertiary Education x Unemployment with Tertiary Education |
|---|---|---|---|---|---|---|---|
| F(1\|0) | 139.89 | 152.72 | 179 | 121.33 | 216.01 | 121.33 | 24.66 |
| F(2\|1) | 24.61 | 33.57 | 17.52 | 34.82 | 45.57 | 34.82 | 46.65 |
| F(3\|2) | 22.25 | 19.61 | 23.64 | 43.59 | 12.8 | 43.59 | 8.62 |
| F(4\|3) | 16.16 | 37.71 | 19.14 | 39.07 | 19.99 | 39.07 | 3.99 |
| F(5\|4) | 12.76 | 11.35 | 7.37 | 25.9 | 28.06 | 25.9 | 9.8 |
| Detected number of breaks: | 4*, 5**, 5*** | 4*, 4**, 5** | 4*, 4**, 4*** | 5*, 5**, 5*** | 5*, 5**, 5*** | 5*, 5**, 5*** | 2*, 2**, 2*** |

Note: The *, **, *** represent the number of breaks detected according to the critical values 1%, 5%, 10% respectively. The critical values for F(1|0): 12.29*; 8.58**; 7.04***. F(2|1): 13.89*; 10.13**; 8.51***. F(3|2): 14.8*; 11.14**; 9.41***. F(4|3): 15.28*; 11.83**; 10.04***; F(5|4): 15.76*; 12.25**; 10.58***.

The Ditzen et al. (2021) test was also conducted in the multivariate context, for the equations. The results can be found in Table 8, which is included in the appendix of this study.

### 5.2 Results of Co-integration Tests

It can be said that any imbalance between the variables is a short-term phenomenon. It is also relevant to the existence of structural breaks in all equations proposed in this study. In Table 4, the results of the ARDL bounds test for the four (6) equations selected are present.

**Table 4 -** ARDL Bounds Test for Investigating Long-Run Equilibrium Relationships

| **Equation** | ARDL Regression | F-statistic | K | Case | t-statistic | Decision |
|---|---|---|---|---|---|---|
| **Eq[a] # 1-:** Economic Growth; Patents per Worker, Gross Fixed Capital Formation, Secondary Education x Employment with Secondary Education | ARDL(1,2,2,0) | 16.39*** | 4 | 3 | -4.580** | YES |
| **Eq[a] # 2-:** Economic Growth Patents per Worker, Gross Fixed Capital Formation, Tertiary Education x Employment with tertiary Education | ARDL(1,2,2,0) | 16.567*** | 4 | 3 | - 4.815** | YES |
| **Eq[a] # 3-:** Economic Growth; Patents per Worker, Gross Fixed Capital Formation, Secondary Education x Unemployment with Secondary Education | ARDL(3,2,2,4) | 7.608** | 4 | 3 | - 3.804** | YES |
| **Eq[a] # 4-:** Economic Growth Patents per Worker, Gross Fixed Capital Formation, Tertiary Education x Unemployment with Tertiary Education | ARDL(3,2,4,0) | 7.383** | 4 | 3 | - 3.916** | YES |
| **Eq[a] # 5-:** Economic Growth; Patents per Worker, Gross Fixed Capital Formation, Secondary Education x Employment with Secondary Education, Secondary Education x Unemployment with Secondary Education | ARDL(2,3,4,3,4) | 14.830*** | 5 | 3 | - 3.921** | YES |
| **Eq[a] # 6-:** Economic Growth Patents per Worker, Gross Fixed Capital Formation, Secondary Education x Employment with Secondary Education, Tertiary Education x Unemployment with Tertiary Education | ARDL(3,4,4,2,4) | 10.503*** | 5 | 3 | -4.466** | YES |

Note: For the bounds test, the asymptotic critical value bounds are taken from Pesaran et al. (2001) and presented by Kripfganz and Schneider (2018) with max lags k in the dependent variable and asterisk. *, **, *** statistical significant at 10%, 5% and 1%, respectively.

Critical values reported for F-statistic and t-statistic are validated with significance; it is only possible to confirm the existence of the long-run relationships proposed. The null hypothesis for all the tests is the existence of no cointegration. The null hypothesis is rejected if both F-statistic and t-statistic are more extreme than the critical values for I (1) variables (if p-values < desired level for I (1) variables included in each ARDL regression. For example, considering the results shown in Equation 6, it was necessary to include the dependent and independent variables, Economic Growth measure, Patents per Worker, Gross Fixed Capital Formation, the interaction between Secondary Education and Employment with Secondary Education, and the interaction between Tertiary Education and Unemployment with Tertiary Education. Based on the critical values for F-statistic and t-statistic with the significance of 1% and 5%, respectively, it can be confirmed that there are long-term relationships for the six equations proposed (see Table 6) to explain the behaviour of Economic Growth in the US, (according to critical values presented by (Kripfganz and Schneider, 2018).

### 5.3. Results for the ADRL Model

Estimations in Table 5 present the ADRL unrestricted error correction model estimation results and report the short-run parameters of the Economic Growth approach, considering the six equations proposed for the analysis of the co-integrated relationships.

**Table 5** - Estimation Results for the ADRL Unrestricted ECM for Economic Growth

| **Short Run** | Equation # 1 | Equation # 2 | Equation # 3 | Equation # 4 | Equation # 5 | Equation # 6 |
|---|---|---|---|---|---|---|
| *LD Economic Growth (GDP)* | | | -0.3165** | -0.4651** | -0.3437* | -0.5874* |
| *LD2 Economic Growth (GDP* | | | -0.2111** | -0.1842** | | -0.0650 |
| *D1* Patents per Worker, | 0.0125 | 0.01195 | 0.0672*** | 0.03108* | 0.0927*** | 0.0816** |
| *LD* Patents per Worker | 0.0431** | 0.044*** | 0.0429** | 0.0342** | 0.03092** | 0.01054 |
| *LD2* Patents per Worker | | | -0.00887 | -0.01967 | -0.05450 | 0.01540 |
| *LD3* Patents per Worker | | | -0.055*** | -0.0348** | -0.0473** | -0.0208** |
| *D1* Gross Fixed Capital Formation | 0.2542*** | 0.2703*** | 0.2337*** | 0.2135*** | 0.2357*** | 0.1646*** |
| *LD* Gross Fixed Capital Formation | 0.073*** | 0.071*** | -0.0638 | 0.04436 | 0.0695** | 0.04216** |
| *LD2* Gross Fixed Capital Formation | | | | | -0.1146** | -0.1126** |
| *D1* Secº Education x Employment with Secº Education | | | | | 0.02413 | 0.06874 |
| *LD* Secº Education x Employment with Secº Education | | | | | 0.04707 | 0.0257 |
| *LD2* Secº Education x Employment with Secº Education | | | | | -0.02947 | |
| D1 Secº Education x Unemployment with Secº Education | | | 0.000269 | | 0.000482 | |
| LD Secº Education x Unemployment with Secº Education | | | -0.0044** | | -0.0056*** | |
| LD2 Secº Education x Unemployment with Secº Education | | | -0.000034 | | -0.001673 | |
| LD3 Secº Education x Unemployment with Secº Education | | | -0.0017** | | -0.0024*** | |
| D1 Tertiary Education x Unemployment with Tertiary Education | | | | | | -0.00375 |
| LD Tertiary Education x Unemployment with Tertiary Education | | | | | | -0.00341 |
| LD2 Tertiary Education x Unemployment with Tertiary Education | | | | | | -0.0055** |
| LD3 Tertiary Education x Unemployment with Tertiary Education | | | | | | -0.00512 |
| *Constant* | 0.8194 | 0.47193 | 0.57080 | 0.91671** | 1.10693 | 2.0916** |
| *ECt-1* | -0.135*** | -0.108*** | -0.162*** | -0.169*** | -0.186*** | -0.174*** |

Notes: *, **, *** mean statistical significance at 10%, 5%, and 1%, respectively. ECT (-1) is the one period lagged co-integrating error term.

#### 5.3.1. Short-term estimates

The results shown in Table 5 reveal the statistical and significant effects of Patents per Worker, Gross Fixed Capital Formation, the interaction between Secondary Education and Unemployment with Secondary Education, and the interaction between Tertiary Education and Unemployment with Tertiary Education. More specifically, the estimated coefficient associated with D. Patents per Worker, according to Equation #5 and Equation #6 in particular, presents a positive and significant short-term effect of 0.0927 % and 0.0816% (at 1% level and 5%, respectively) on Economic Growth measure (GDP); while, the coefficients of D (L Patents per Worker (-1)), it is possible to conclude in year time t -1 when this variable increase by 1%, it will contribute to a statistically and significant increase of 0.0429% (Equation #3) 0.0342% (Equation #4) and 0.00309% (Equation #5) on Economic Growth at the 5% level in the previous year, respectively. Other of the hand, D. Gross Fixed Capital Formation, according to Equation #5 and Equation #6, presents a positive and significant effect of 0.235 % and 0.1646% on the Economic Growth measure (GDP) at a 1% level, respectively. In year period t -1, if Gross Fixed Capital Formation increases by 1%, it will contribute to a statistically significant increase of 0.0695% (Equation #5) and 0.0421% (Equation #6) in Economic Growth, at a 5% level in a previous year, respectively. However, a shock in year t-1, that is, if the iterative effect between Secondary Education and Unemployment with Secondary Education grows to 1% in the previous year, it is estimated that this contributes to the Economic Growth decrease of -0.0044% (Equation #3) and -0.0056 (Equation #5) in the previous year, respectively, with 5% significance. The shock of the interactive effect between Tertiary Education and Unemployment with Tertiary Education in the t -2 yearly increase by 1%, according to Equation #6, will contribute to a statistically significant decrease (at 5% level) of 0.0055 in Economic Growth.

Other of the hand, analyzing the results of the six estimated equations, it is observed that the coefficient associated with the error correction term ECT (-1) is negative and statistically significant at a level of 1% significance; therefore, any short-term imbalance between the Economic Growth measure (GDP) and explanatory categorical Education level and their interaction with Employment and Unemployment selected and Technological Progress converge on the long-term equilibrium relationship. In the case of the ADRL model applied to Economic Growth in the United States, it means that any deviation from the long-term equilibrium between the variables is corrected by about 13.5 % and 10.8% (according to Equations #1 and #2) and 16.2% and 16.9%, (according to Equations #3 and #4) and 18.6% and 17.4%, (according to Equations #5 and #6) respectively. For example, in Equation #5, about 18.6% of the imbalances in the Economic Growth, due to a certain shock in the previous year, converge back to the long-term balance in the current year.

### 5.3.2. Long-term estimates

Estimations in Table 6 present the ADRL unrestricted error correction model estimation results and reports the long-run parameters of the Economic Growth approach. Considering all six equations, the variable Gross Fixed Capital Formation, in the long term, in terms of effect magnitudes, is the only one that presents the greatest positive and significant effect (at a significance level of 1%) on Economic Growth. That is, to say, for example, according to Equation #5 and Equation #6, an increase of 1% in Gross Fixed Capital Formation provokes an increase of 0.7877% and 0.7946% in Economic Growth, respectively.

**Table 6** - Estimation results for the ADRL Unrestricted ECM estimation results for Economic Growth

| ***Long Run*** | Equation #1 | Equation # 2 | Equation # 3 | Equation #4 | Equation # 5 | Equation# 6 |
|---|---|---|---|---|---|---|
| Patents per Worker | 0.00468 | 0.00801 | -0.03615 | 0.09200 | -0.04329 | -0.0653 |
| Gross Fixed Capital Formation | 0.6766*** | 0.7886** | 0.7559*** | 0.6183*** | 0.7877*** | 0.7946*** |
| Sec° Education x Employment with Sec° Education | -0.13212 | | | | -0.2518 | -0.79818 |
| Tertiary Education x Employment with Tertiary Education | | -0.07827 | | | | |
| Sec° Education x Unemployment with Sec° Education | | | -0.00027 | | 0.00460 | |
| Tertiary Education x Unemployment with Tertiary Education | | | | -0.0272** | | -0.0084** |
| $R^2$ | 0.9426 | 0.9430 | 0.9735 | 0.9619 | 0.9799 | 0.9735 |
| *Adjust* $R^2$ | 0.9249 | 0.9255 | 0.9499 | 0.9411 | 0.9513 | 0.9307 |

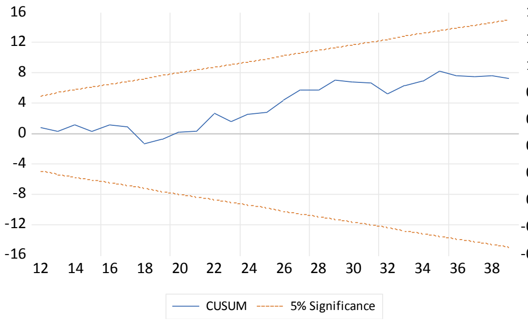
Notes: *, **, *** mean statistical significance at 10%, 5%, and 1%, respectively

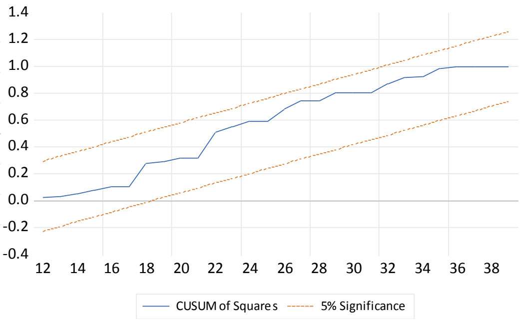
In turn, considering the interaction between Tertiary Education and Unemployment with Tertiary Education, there appears to be a negative and significant lowest magnitude effect on Economic Growth at the 5% statistical level. Thus, according to the same Equation, # 4 and Equation # 6, an increase of 1% in the interaction between Tertiary Education and Unemployment with Tertiary Education provoked a decrease of 0.0272% and 0.0084% in Economic Growth, respectively. The overall adjustment for both of the six equations to explain Economic Growth shows the highest values range between 92.49% (Equation # 1) and 95.13% (Equation # 5), considering the measure of adjustment R-square.

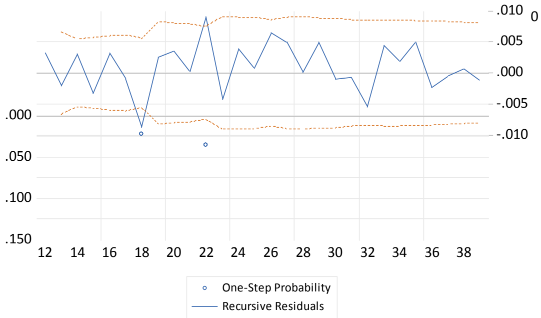
### 5.4 Stability and Diagnostic test

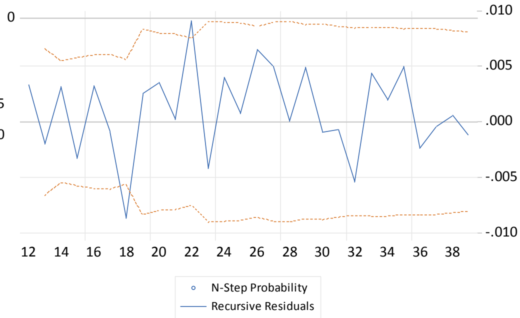
In this section, the Cumulative Sum Control Chart (CUSUM) and the Cumulative Sum of Squares (CUSUMSQ), One-Step Forecast, N-Step Forecast and Recursive Residuals, respectively to assess the stability of the equations is introduced.

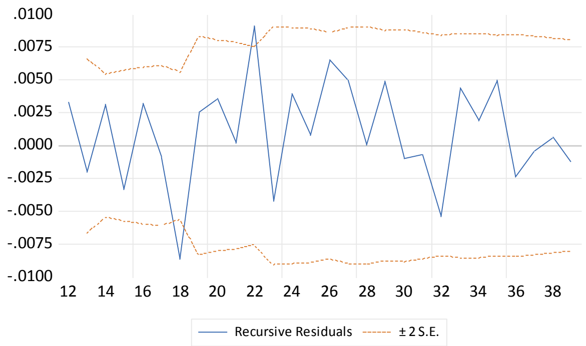
# Equation #1



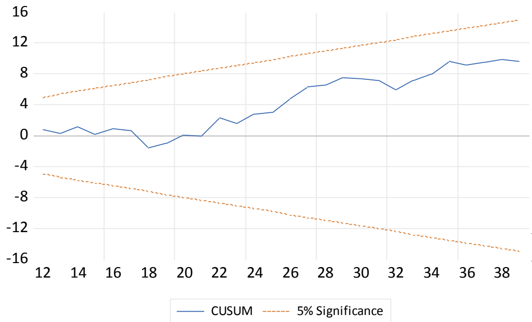



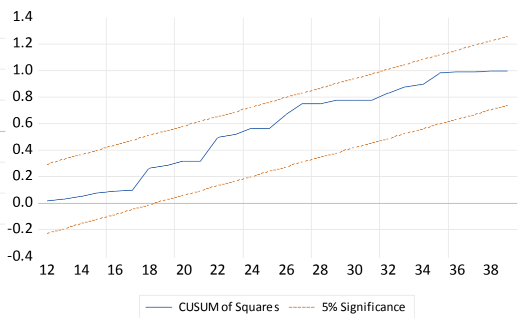



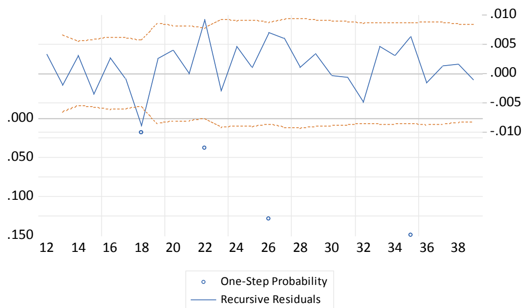



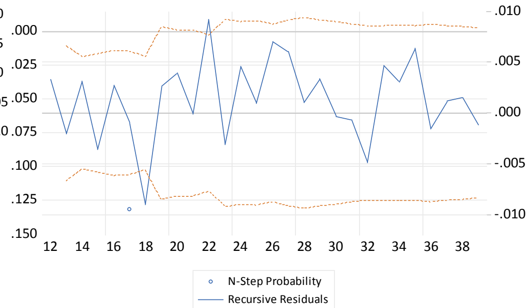



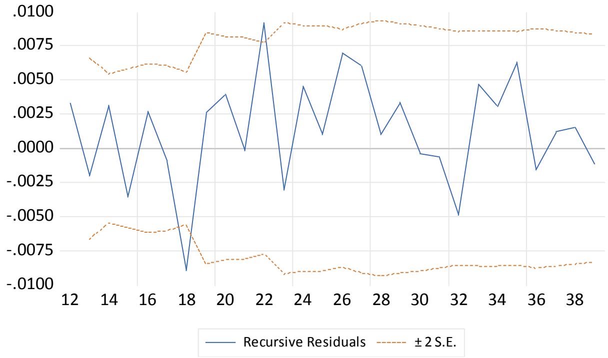

# Equation #2



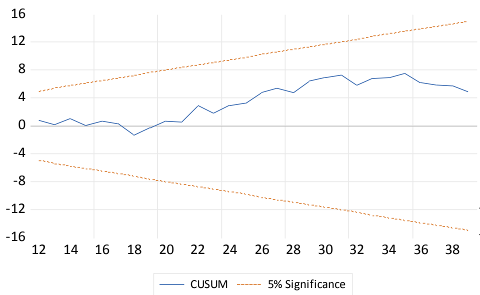



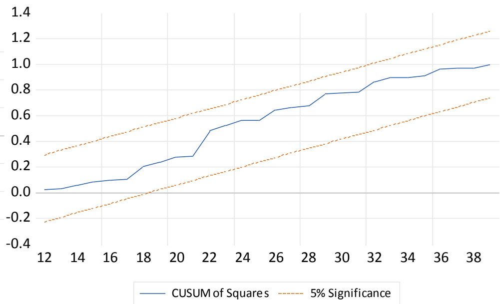



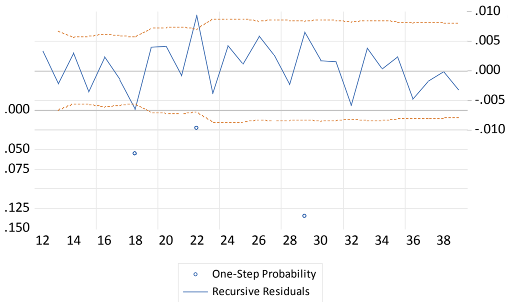



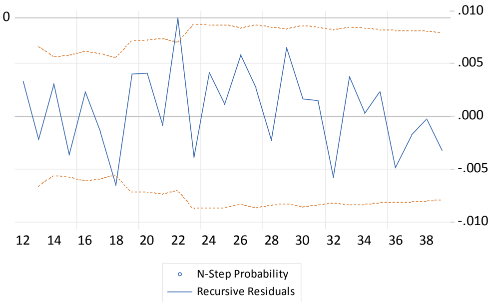

Recursive Residuals
± 2 S.E.

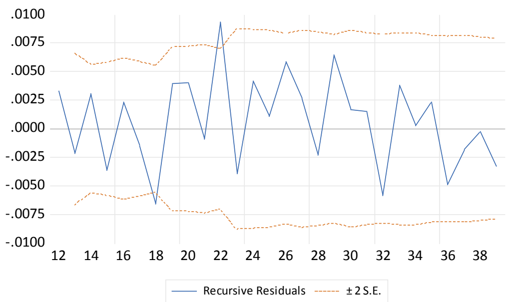
# Equation #3


CUSUM
5% Significance

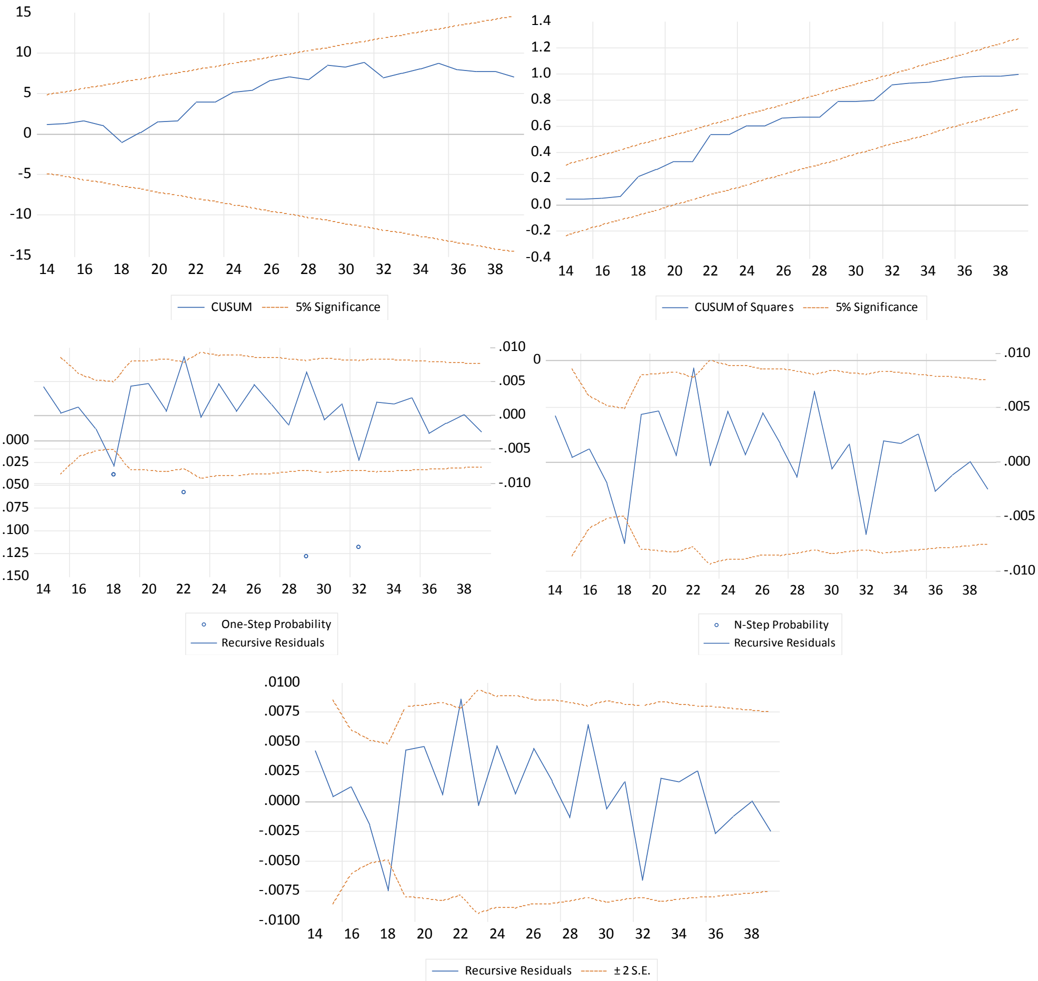

CUSUM of Squares
5% Significance


One-Step Probability
Recursive Residuals

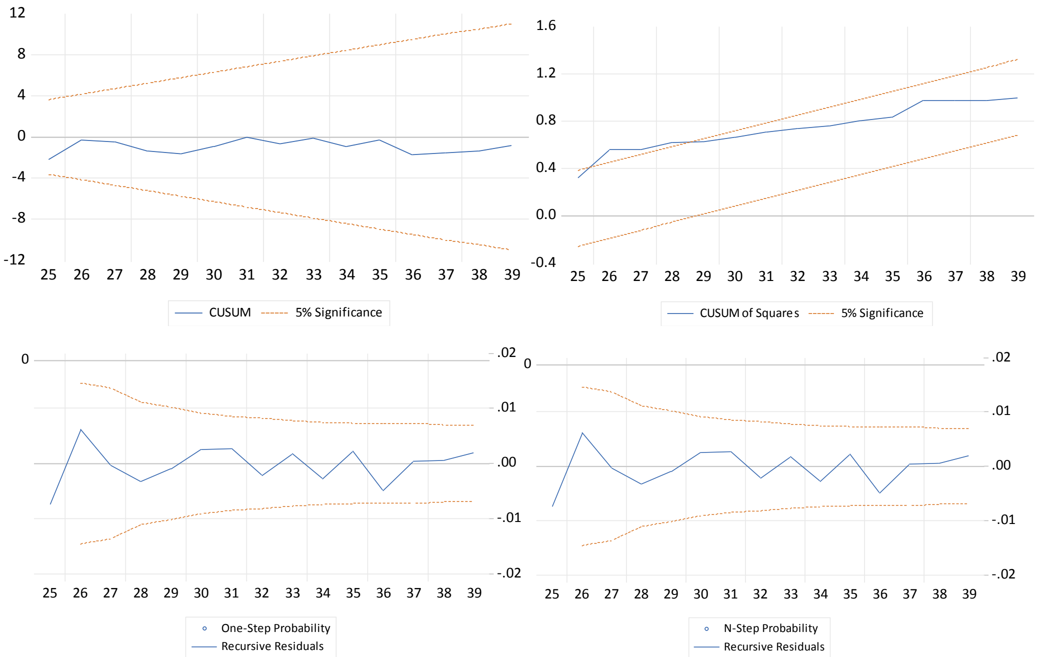

N-Step Probability
Recursive Residuals

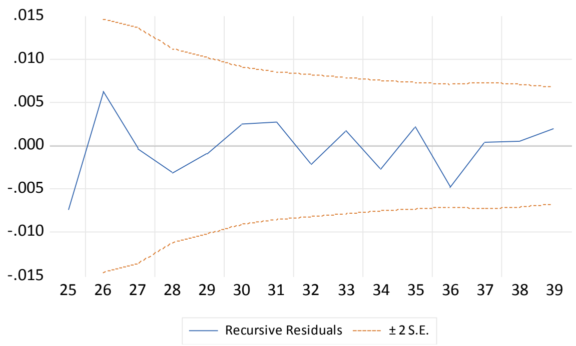

Recursive Residuals
± 2 S.E.

# Equation #4

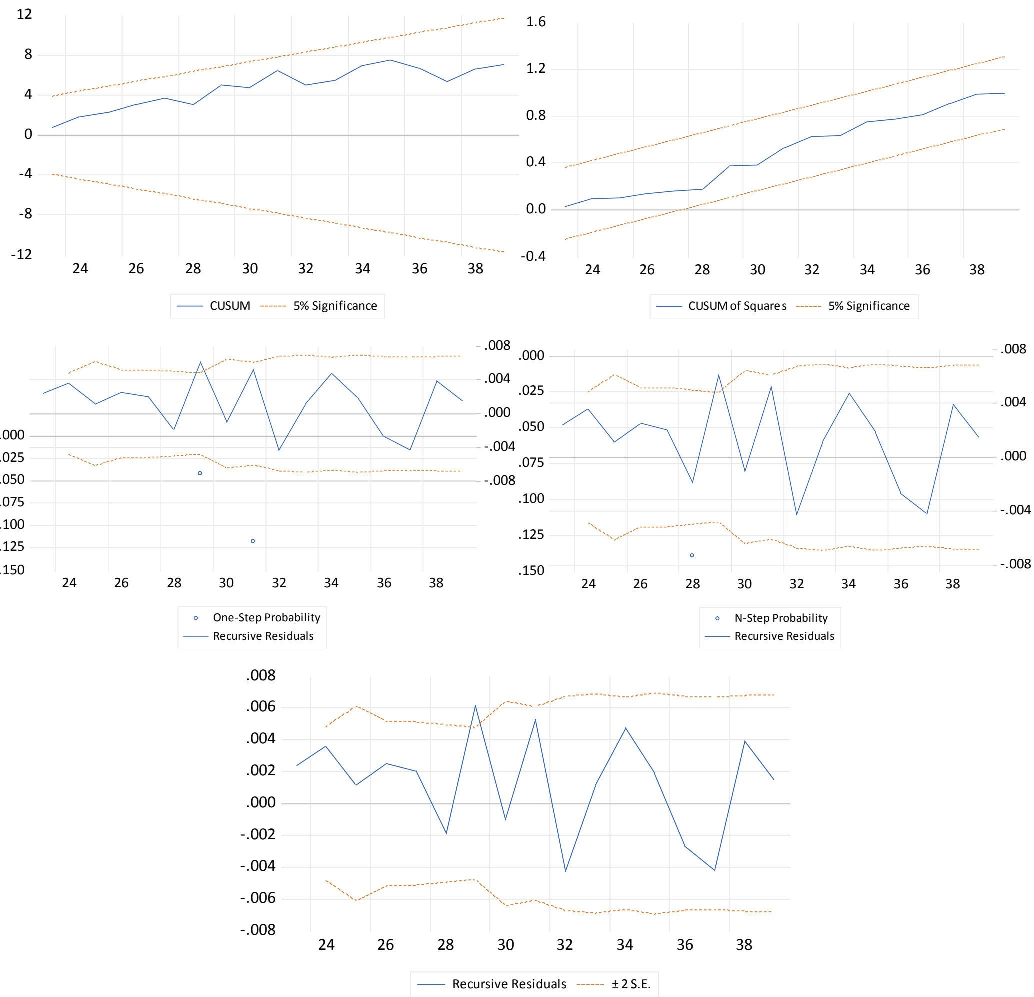



# Equation #5






Equation #6




### 5.5. Discussion and Policy Implications

#### 5.5.1. Discussion

The estimated model in this study is an augmented version of endogenous growth, which is based on $Y = AK$, i.e., the product is a result of technological progress $(A)$ and capital $(K)$. Therefore, it is not surprising that the variable Patents Application (the number of patents applications by residents and non-residents) per Worker positively affects economic activity in the short run. This situation can be interpreted as a proxy for technical progress or innovation converging with the model proposed by (Romer, 1990) and the (Fatimah et al., 2021) study, but this relationship is only observed in the short run. This finding provides support for the proposition that technological advancements and the emergence of novel concepts can enhance productivity and stimulate economic activity. As previously mentioned, it should be noted that this association is limited to the short term, implying that the influence of patent applications per worker on economic activity may diminish or undergo a shift in nature over time as the economy adapts and additional factors come into consideration.

Similarly, Gross Fixed Capital Formation has the same relationship with GDP since it is an element that makes up the $K$, and so, as previously said, the product depends on parts of this variable to expand, corroborating with the study findings (Turna and Ceylan, 2022) and the current macroeconomic theory. It is important to say that this relationship was found in both the short and long run.

In the short run, Equations #5 and #6 point to an inverse relationship between the interaction of secondary education and the unemployment of these individuals ($HE_{at} * U_{at}$), and the tertiary education and the level of unemployment in these individuals ($HE_{bt} * U_{bt}$) on the GDP. This finding aligns with the concept of Okun's Law, which posits an inverse relationship between unemployment and economic activity; however, it is important to note that the magnitude of the expected decline in economic activity due to unemployment is not as pronounced as predicted by Okun's Law however. Evidence is in place to not validate. On the other hand, in this research, unemployment is not the only consideration; other variables are included that measure, in a sense, human capital and labour. Thus, this reduced impact of unemployment on the economic activity effect of human capital corroborates with the studies of (Adeleye et al., 2022; Agasisti and Bertoletti, 2022; Fatimah et al., 2021; Majidi, 2017; Matousek and Tzeremes, 2021; Shidong et al., 2022; Zafar et al., 2019). Despite arguing that the Okun law is not valid in the proportion foreseen by the author, however, it cannot be denied that the described effect is observed, which agrees with the studies (Altunöz, 2019; Daniela et al., 2019; Dritsakis and Stamatiou, 2018; Ikechukwu, 2017; Nagel, 2015; Okur et al., 2018; Pasara and Garidzirai, 2020; Sharma and Sharma, 2019).

On the other hand, the study (Maitra, 2016) also shows that human capital positively affects the economy, but the effect of the increase in the workforce is more quickly observed. The observed result that the relationship between tertiary education and unemployment, despite a negative effect in this sample, is indicative that in the long run, the effect of human capital is more lasting. This conclusion was reached when the relationship between secondary education and unemployment proved not to be statistically significant. Therefore, this evidence corroborates with the studies (Baldwin et al., 2011; N. Baldwin and Borrelli, 2008; Bowen and Qian, 2017; Faggian et al., 2017; Fan et al., 2016; Jorgenson and Fraumeni, 1992; Turna and Ceylan, 2022), which show that sustainable growth is directly linked to the available human capital, including one of the reasons for the difference in economic levels between nations. Therefore, it reinforces the model of endogenous growth proposed by (Lucas, 1988), in which the increase in output is related to the availability and increase of human capital in the economy.

### 5.5.2. Policy Implications

The results of this study can contribute to better analysis and reflection on present policies oriented or implemented in the US labour market and define future strategies for the job search and unemployment side to contribute to and stimulate Economic Growth. Government policies in the different States of the US should be unanimous. Support of, and the subsidization of financing for Students in Higher Education, should be implicit in the decision-making process to combat the abandonment of this potential skilled workforce. The measurement in terms of not only quantitative but also qualitative of education in the US constitutes an important driver besides the demand function and a critical response mechanism to technological progress and innovation, contributing to and stimulating its effect on the final product, which is the growth of the economy. When the effect of education on supply in the labour market is considered, this will translate into productivity growth, provided there is public investment in infrastructure and innovation to ensure that the country has a sustained physical and human capital base. Thus, the promotion of qualified employees and the reduction of unemployment in the working population with tertiary education, in the short term, per se, will constitute a policy instrument that will contribute to economic growth. Integrating employment and skilled labour helps to maximise the benefits for workers and to ensure that their contributions to economic growth are sustainable and inclusive. Moreover, it can be said that if political decision-makers do not address unemployment, especially in times of crisis, regardless of its nature, economic, financial, or pandemic, it may persist and pose serious social and economic problems. Especially if periods of unemployment are prolonged, unemployed workers, in particular those with Secondary and Tertiary Education, lose valuable professional skills and therefore remain unemployed. Since there is a dependence between the trajectories in the behaviour of economic growth, employment, and unemployment, measures that promote employment and reduce unemployment are vital. Therefore, a combination of structural and demand-driven policies must be implemented to reduce unemployment, in particular, to halt protracted recessions. From the political point of view, the presence of hysteresis in recessions implies that Keynesian policies oriented by the demand for work are relevant in the fight against long-term unemployment.

## 6. Conclusions

This paper analysed the role of technological progress and physical and human capital effectiveness as key determinants of economic growth from 1981-2019 in the United States. In the long term, when the results of ARDL estimation were considered, the variable Gross Fixed Capital Formation provoked a higher and positive effect on Economic Growth. However, in turn, considering the interaction between Tertiary Education and Unemployment with Tertiary Education, a negative and significant lowest magnitude effect on Economic Growth is present. Moreover, when the results of all estimated equations were analysed, it was observed that the coefficient associated with the error correction term ECT (-1) is negative and statistically significant at a level of 1% significance. In the short term, the results show statistical and significant effects of Patents per Worker, Gross Fixed Capital Formation, the interaction between Secondary Education and Unemployment with Secondary Education, and the interaction between Tertiary Education and Unemployment with Tertiary Education. In the short term, there is a dependence between the trajectories in the behaviour of economic growth, employment, and unemployment, measures that promote employment and reduce unemployment. The parameter estimates of those drivers determine the level of economic growth in the short and long run. Indeed, in the short term, and particularly after an economic crisis, when the effect of education at the secondary level is relatively low, and much of the labour force is unemployed, many people decide to stop after completing secondary education. At times like this, and in terms of policy implications, the governments in regional states of the US decide to invest only in physical capital, and consequently, then, the aggregate output would present higher growth provoked by physical capital, according to our results. This would bring higher returns with an immediate effect on secondary education and employment, discouraging individuals from going to tertiary education, and consequently, the effect of this level of education on employment is positive and increases economic growth. Conversely, in the long term, when the tertiary-level educational effect on unemployment is significant, the resultant effect on economic growth is negative and low.

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## Appendix

**Table 7 -** Clemente-Montañés-Reyes (1998) Unit-Root Test with Double Mean Shifts

| Variables | At level | | | | At 1st difference | | | |
|---|---|---|---|---|---|---|---|---|
| | Du1 | Du2 | Rho - 1 | Optimal Breakpoint | Du1 | Du2 | Rho - 1 | Optimal Breakpoint |
| Economic Growth (GDP) | 0.440*** | 0.214*** | -0.292 | 1996, 2007 | -0.00582 | -0.013** | -0.991 | 1989, 2007 |
| Patents Application (Ideas) per Worker | 14837.25*** | 18178.34*** | -1.841 | 1996, 2007 | 1064.158*** | -457.819 | -1.297 | 1996, 2010 |
| Gross Fixed Capital Formation | 0.61881*** | 0.248*** | -0.419 | 1996, 2013 | -0.002 | -0.021 | -0.593 | 1989, 2007 |
| Secondary Education x Employment with Secondary Education | -0.479*** | -0.716*** | -0.451 | 1993, 2006 | -0.109** | 0.011 | -1.823 | 1990, 2007 |
| Tertiary Education x Employment with Higher Education | 1.89278*** | 0.722*** | -0.405 | 1993, 2003 | -0.091 | 0.022 | -0.163 | 1984, 2000 |
| Secondary Education x Unemployment with Secondary Education | 9.925*** | -14.214*** | -0.62 | 2010, 2014 | 0.634 | -0.192 | -0.942 | 1989, 2007 |
| Tertiary Education x Unemployment with Tertiary Education | 4.917*** | -4.752** | -0.67 | 2005, 2016 | -0.006 | -0.021 | -0.845 | 1989, 2007 |

Note: the level of statistical significance of 1% is denoted by *** and 5% is denoted by ** and 10% by *

**Table 8 -** Sequential Test for Multiple Breaks at Unknown Breakpoints Ditzen et al. (2021) for the Equations

| | Equation #1 | Equation #2 | Equation #3 | Equation #4 | Eqaution #5 | Equation #6 |
|---|---|---|---|---|---|---|
| F(1\|0) | 67.52 | 14.3 | 50.58 | 33.1 | 17.07 | 20.15 |
| F(2\|1) | 463.41 | 31.73 | 312.21 | 311.81 | 3.87 | 36.04 |
| F(3\|2) | 24.45 | 502.04 | 184.91 | 185.24 | 74.84 | 1.22 |
| F(4\|3) | 13.48 | 236.55 | 479251.39 | 247.44 | 25.36 | 0.77 |
| F(5\|4) | 651.59 | 38639.27 | 277992.49 | 13724.07 | -0.39 | 31.76 |
| Detected number of breaks: | 5*, 5**, 5*** | 5*, 5**, 5*** | 5*, 5**, 5*** | 5*, 5**, 5*** | 4*, 4**, 4*** | 5*, 5**, 5*** |

Note: Note: The *, **, *** represent the number of breaks detected according to the critical values 1%, 5%, 10% respectively. The critical values for F(1|0): 12.29*; 8.58**; 7.04***. F(2|1): 13.89*; 10.13**; 8.51***. F(3|2): 14.8*; 11.14**; 9.41***. F(4|3): 15.28*; 11.83**; 10.04***; F(5|4): 15.76*; 12.25**; 10.58***.

**4The Augmented and Integrative Model of Economic Growth: Theoretical and Empirical evidence from USA**

**Victor Moutinho**[1a*] Management and Economics Department and NECE-UBI, University of Beira Interior Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal, ferreira.moutinho@ubi.pt ; **ORCID -** 0000-0003-0811-9033

**Biography Note**

PhD in Energy Systems and Climate Change from the University of Aveiro. Since October 2019 he is a Assistant Professor at the Department of Management and Economics of the University of Beira Interior, Portugal. He holds a BSc in Economics from Faculty of Economy of Porto and MSc in Finance (University Portucalense of Porto, Portugal). Since December 2021 he is Director of the Master in Economics at University of Beira Interior (UBI). He is Coordinator of Economics and Finance and Full Researcher at NECE - Research Center in Business Sciences at the UBI. He has published articles in peer - reviewed journals on energy economics and policy and has participated in several conferences and international projects. Its areas of interest are Energy Economics, Environmental and Natural Resources Economics, Energy Policy, Development and Sustainability. Associate Editor at Environmental Development and Sustainability (Springer). Member of IAEE (International Association of Economists of Energy) and Member of APEEN - Portuguese Association of Energy Economics.

**Helena Santos de Oliveira**[1b] Accounting and Management Department and CEOS.PP, Polytechnic Porto, School of Accounting and Administration of Porto and NECE-UBI, University of Beira Interior, Portugal, oliveira@iscap.ipp.pt; **ORCID -** 0000-0001-8153-9005

**Biography Note**

Ph.D. in Financial Economics and Accounting since 2015, University of Vigo; Master in Finance, Portucalense University of Porto; Bachelor in Accounting and Administration - Financial Control, School of Accounting and Administration of Porto (ISCAP/IPP).

Professor of Accounting and Management at ISCAP/IPP since 2000. Research NECE-Research Center in Business Sciences, Management and Economics of the University of Beira Interior, Department of Management and Economics, University of Beira Interior, Covilhã, Portugal, Center for Organizational and Social Studies of Polytechnic Porto, Center for the Study of Population, Economics and Society. My research interests are Financial and International Accounting, Earnings Management, Ethic and Corporate Governance, and Financial Economics with several articles published in scientific journals and national and international conferences. Peer reviewer and member of scientific committees in national and international journals. Director of the Portuguese Association of Accountants, Member of the General Counsel of the Accounting Standards Commission and Member British Accounting and Finance Association(BAFA).

**Henrique Espinosa,** [1c] Management and Economics Department, University of Beira Interior, Rua Marquês d'Ávila e Bolama, 6201-001, Covilhã, Portugal, henrique.oliveira@ubi.pt
**ORCID -** 0000-0002-8364-8069

**Biography Note**
Currently, is a Ph.D. student at the University of Beira Interior (UBI), and has developed research in the area of economic growth, energy consumption, and, economic relations between countries. Has an interest in developing research in the areas of macroeconomics, institutional economy, international economy, and consumption of renewable and non-renewable energies. I have publications at Energy Reports, Energies, and presentations of papers at conferences such as ICEER and APEEN.

**Félix Puime,** [1d] Business Department of the University of A Coruña, Spain. felix.puime@udc.es
**ORCID -** 0000-0001-7341-9134

**Biography Note**
Bachelor of C.C. Economics and Business Studies from the University of Santiago de Compostela. Ph.D in Business Administration and Management from the University of Vigo. Professor of the Business Department of the University of A Coruña. Author of numerous publications in journals specialized in finance. Speaker at national and international scientific conferences. He has more than 35 years of professional experience as a manager and consultant in the business world in the field of corporate finance, both nationally and internationally.

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## Credit Author Statement

**Victor Moutinho**: Conceptualization, Investigation, Writing Original Draft, Data Curation, Methodology, Software, Visualization, Supervision.
**Helena S. de Oliveira**: Writing, Investigation, Data Curation, Formal analysis, Validation, Reviewing and Editing.
**Henrique Espinosa:** Writing, Investigation, Methodology, Data Curation, Visualization.
**Félix Puime:** Investigation, Formal analysis, Validation, Reviewing and Editing, Supervision.