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Impact Of Public Expenditure on Science and Technology, Education, and Innovation on Economic Growth in Latin America, 1990 – 2022

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ABSTRACT

Purpose: To analyze to what extent public spending impacts the economic growth of Latin America, 1990 – 2022. Design/Methodology/Approach: A quantitative approach methodology, basic type, non-experimental design with longitudinal section and explanatory level was used. The analysis sample was between 1990 and 2022. Likewise, for the preparation of the thesis, the following data documents were used: World Bank Data and Real GDP Data 1990 to 2022. The technique employed involved documentary analysis, supported by an instrument specifically developed to guide the process. Findings: The results identified a positive and significant correlation between the variables science and technology, education and innovation, and GDP growth; the p-value was less than 0.05 for the established hypothesis tests. Furthermore, an R-squared of 0.9621 was found, and Fisher's F test was equivalent to 0.000, demonstrating the overall relevance of the model. Thus, the findings were in greater agreement with Zhong (2021), who mentions that government spending on science and technology has an important impact on economic development. Conclusions: There is an effect of public spending related to science and technology, Education and Scientific Innovation on the economic growth of Latin America during the period 1990 - 2022, which was verified using Fisher's F test.
Originality/value: The study was grounded in the use of updated data and a comparative approach across sectors; its value lies in providing a critical overview of the status of the variables studied in Latin America.

Keywords: spending, science, technology, education, innovation, growth

JEL. Classification: H5, O31, O32, H52, F43, E23

INTRODUCTION

In the international context, several countries have seen a decline in returns on both macroeconomic and capital investments. Given this situation, these economies depend on investments in essential areas such as health, science, and technology, which guarantee a constant supply of inputs and an efficient labor market (Hu & Wang, 2024).

Therefore, the level of spending on research and development (R&D) is one of the key indicators for measuring a country's progress in innovation and technology. Between 2000 and 2017, global spending on R&D increased significantly, multiplying by approximately 2.5, which shows that the growth and pursuit of knowledge is constantly evolving and growing. However, this increase was concentrated mainly in developed countries such as the United States, China, Russia, and several European countries. Only China and the United States have managed to compete in increasing their R&D investments, leaving Latin America behind (Colombo & De Angelis, 2021).

Indeed, it is evident that there is a lag in Latin America and the Caribbean regarding R&D expenditure, compared to advanced and emerging economies. Over time, Latin America continues to be unable to narrow this inequality in research and development; on the contrary, it has widened. For example, the United States allocates 3% of its Gross Domestic Product (GDP) to R&D, increasing this percentage by 0.2% between 2013 and 2019. On the other hand, Latin America and the Caribbean spend four times less, which has also decreased from 0.65% in 2013 to 0.56% in 2019 (Economic Commission for Latin America and the Caribbean [ECLAC], 2022).

At the national level, Peru ranks below the average for Latin American economies in terms of the number of academics. Specifically, it is positioned lower than countries with similar characteristics in Latin America and the Caribbean, and very far from economies that are members of the OECD. Internationally, the country shows a significant lag in this indicator. It is estimated that only 0.2% of the EAP (Economically Active Population) is interested in research, which places Peru below the regional average (Espinoza & Morales, 2021).

In this regard, despite advances in human capital and research, Peru still faces challenges in knowledge creation, technological development, and the promotion of new businesses. However, it moved up in the Global Innovation Index. According to Table 1, in the current edition, the country reached 75th place, surpassing its position in 2023 (76th out of 132). However, despite this increase, its ranking remains below that of Brazil (50th), Chile (51st), Mexico (56th) and Uruguay (62nd) (Peruvian Foreign Trade Society [COMEXPerú], 2024).

Table 1. Peru's Position in the 2024 Latin America Innovation Index

Country	Position
Brazil	50
Chile	51
Mexico	56
Colombia	61
Uruguay	62
Peru	75
Argentina	76
Paraguay	93
Bolivia	100
Ecuador	105

Source: Adapted from COMEXPerú (2024)

Furthermore, the business sophistication pillar experienced the worst performance compared to the previous year, dropping from position 52 in 2023 to 77 in 2024. This setback is mainly caused by the low R&D investment, an indicator that was not recorded for Peru in the previous edition. The most recent update of this indicator reveals that Peruvian companies allocate approximately 0.04% of GDP to R&D, compared to the 0.2% and 0.1% invested by Argentina and Chile, respectively. On the other hand, in high-income economies, this percentage reaches an average of 2% of GDP, according to the GII 2024 (COMEXPerú, 2024).

When comparing Colombia with Peru, we see that Peru invests 0.24% of its GDP in R&D, ranking seventh in the list of highest investment in this area. Furthermore, Colombia is ranked seventh among the nine countries with the highest number of research projects per million inhabitants. In terms of patents granted to residents per million inhabitants, Colombia ranks fourth, surpassed by Brazil, Argentina and Mexico. Likewise, it allocates 27% of its budget to the transportation sector, 21% to statistical information and 15% to science, technology, and innovation. Therefore, Colombia is more developed in terms of Science and Technology (S&T) compared to Peru (Private Council for Competitiveness, 2022).

Regarding Chile, total R&D expenditure grew from 0.36% to **0.39% of GDP**, a large part of this increase came from universities and the business sector, with a participation of 42% each. The number of academics increased to 2,513, of which 33% work in the private sector. Although the country continues to lead the region, it is still far from the OECD average, which is 2.72% of GDP. In monetary terms, R&D expenditure is equivalent to MM$1,031,448. At constant prices, an increase of 10.7% (MM$92,390) was recorded compared to 2021, which shows real growth even when considering the impact of inflation (Ministry of Science, Technology and Innovation [MCTI], 2024).

Similarly, Mexico allocates an average of 73 billion pesos to R&D, which represents about 0.31% of its GDP, a much lower figure than the 0.47% recorded the previous year. This indicator demonstrates limited government commitment to scientific research and development. On the other hand, although the country, along with Brazil, has a large number of academics, public reports, and scientific innovations, it ranks on average below Latin America and the Caribbean. This is mainly due to the lack of budget allocation from the government, the inefficient use of resources, and the low execution of regional expenditure on science, research, and technology (Canales, 2022).

Regarding Uruguay, in the last three years, both R&D/GDP and S&T/GDP investment have remained relatively stable, reaching values of 0.44% and 0.75%, respectively. Although the percentage allocated to R&D/GDP is considerably below leading countries like South Korea, Israel, or the United States, which exceed 3%. On the other hand, this value is close to the weighted average for Latin America and the Caribbean, calculated at 0.65%. In 2022, investments allocated to S&T activities at the national level reached a historical record of $680 million, which is an increase of 28% compared to 2021, when 150 million current dollars were recorded (National Agency for Research and Innovation [ANII], 2024).

On the other hand, Ecuador has a low investment in innovation, equivalent to 0.47% of its GDP. Of this total, 74.4% comes from the private sector, while only 5% corresponds to the government. This low participation shows a lag in innovation within the region. According to the Ingenios Code, a minimum investment of 0.55% of GDP in R&D initiatives was established as a goal, a goal that is currently not being met. This failure represents a low capacity to generate knowledge and technology, which limits GDP growth in the country (Espín, 2021).

In Ecuador, public expenditure allocated to science, technology, and innovation is almost null, since the government only provides funding equivalent to $6 million, a figure that was barely 0.03% of GDP in 2019. This scarce investment limited the development of research, which has been sustained mainly by universities, thanks to resources from abroad, such as the case of Spain, a country that has financed and sustained up to 40% of these activities. Despite this, Ecuador has invested in higher education in order to further develop research, allocating approximately 319 million dollars in 2020, however, in 2019 this budget was reduced, constantly decreasing over the years. Subsequently, in 2020, 37 million were cut, and during the Covid-19 pandemic, funding was reduced by 98 million dollars. As a consequence, many public universities are at risk of sustainability. An example of this is the last cut of 5% of the total annual budget allocated to universities (Espín, 2021). For this reason, in terms of research, the following question has been posed: How does public expenditure on science and technology, education, and innovation impact the economic growth of Latin America, 1990-2022?

LITERATURE REVIEW

Theoretical Aspects

Adam Smith's Theory of Public Expenditure

Adam Smith (1776), in his work *The Wealth of Nations*, argues for the importance of keeping public expenditure at low levels, allocating it only to essential areas and strictly for the well-being of individuals. According to Smith (1776), this expenditure should focus on three main functions for the proper functioning of the state and the protection of the economy:

Defense and security: It consists of protecting society from external threats by financing a national defense. This type of expenditure ensures the country's stability and the protection of its citizens (Smith, 1776).

Justice and judicial system: Its objective is to safeguard the population from injustice and oppression, ensuring the security of property and individual rights. This implies maintaining an efficient and accessible judicial system to resolve conflicts and punish crimes, which requires investment in legal and judicial infrastructure (Smith, 1776).

Public works in education and infrastructure: This includes the financing of works and infrastructure that benefit society as a whole, such as roads, bridges, and other projects that facilitate trade and are not profitable for private initiative. These works must fulfill a clear public function and be accessible to all, supporting the country's economic growth and development (Smith, 1776).

Endogenous Growth Model

The endogenous growth model emerges as an alternative to neoclassical theory, explaining growth through internal conditions such as: human capital, innovation, and public policies. This contrasts with classical theory, which incorporates mechanisms that operate within the system itself. Jiménez (2011) identifies three fundamental aspects that endogenous models seek to clarify. First, they explain why developed economies have managed to sustain higher levels of production than those identified a century ago. In this context, Romer (1990) indicates that productivity per hour worked in the United States multiplied by ten during the last century, mainly attributing this growth to technological advancement.

Secondly, the goal is to understand the growth of human capital, that is, how the workforce has improved its capacity thanks to advances in education and technology. Finally, the aim is to understand why the world's economies maintain structural differences in their growth rates (Jiménez, 2011).

While exogenous growth models explain long-term growth through technological progress, endogenous models do not incorporate it directly, so it must be assumed as an exogenous variable. To address this limitation, the AK endogenous growth model is used, whose dynamics are modeled using the following production function:

$$Y = A\,k$$

Where Y is the aggregate output and A is a parameter that incorporates technology. If we assume that the assumptions of the Solow–Swan model are met, then:

$$\dot{k} = sf(k) - (n + \delta)\,k$$

Since f(k)=A k, we obtain:

$$\dot{k} = sAk - (n + \delta)\,k$$

Expressed in terms of growth rates:

$$\gamma_k = \frac{\dot{k}}{k} = sA - (n + \delta)$$

According to Jiménez (2011), endogenous growth models are divided into two generations. The first is comprised of the Harrod-Domar, Solow-Swan, Frankel, and Arrow models. The second generation includes the pseudo-Harrod-Domar, neo-exogenous, Romer, and Lucas models.

Solow–Swan Model

According to Jiménez (2011), the Solow–Swan model incorporates fundamental variables such as productivity and capital, with the purpose of representing economic growth through a mathematical equation. This theory is based on the productive capacity of each country. Production is measured in per capita terms, and the assumption is that savings equal investment. Its main objective is to represent the dynamics of production by integrating factors such as physical capital and the savings rate in the economy.

Below, we will examine the assumptions of the Solow model and the fundamental equation.

Assumptions:

- ✓ Production is represented as a Cobb–Douglas function.
- ✓ A homogeneous good (single good) is produced, intended for consumption and saving:

$$Y = C + I$$

- ✓ Investment equals saving (Saving automatically converts into investment).
- ✓ Economic agents have a constant saving rate

$$S = s\,Y,\ 0 < s < 1$$

Therefore:

$$C = (1 - s)\,Y$$

- ✓ The growth rate of the population is equal to the growth rate of the EAP.
- ✓ Net investment is gross investment minus depreciation.
- ✓ Technology is exogenous and there is no technological change.

Solow's Fundamental Equation:

$$\dot{k} = sy - (n + \delta)k$$

Where:

sy: Available saving

$(n + \delta)k$: Necessary investment

According to Mendoza (2018), the Slow–Swan model is based on two simple equations. The first is a neoclassical production function, commonly expressed as a Cobb-Douglas, which connects the product per capita with the capital-labor intensity, under the assumption of diminishing returns. The second equation corresponds to the **saving-investment identity** in a closed economy without state participation, where capital accumulation is defined as the difference between investment and depreciation.

In this context, resources for gross investment come from household savings, which originate from income not allocated to consumption. Mendoza (2018) points out that the dynamics of capital per worker follow a particular pattern, as they increase when investment exceeds the depreciation of physical capital, while they decrease when an adverse situation occurs, i.e., when depreciation exceeds investment.

Additionally, Mendoza (2018) mentions that, although in simple economic growth models technological progress is considered an external factor (i.e., not explained in the model), Solow's proposal was fundamental to the advancement of research in recent years. In fact, it gave rise to what is known as the convergence literature, which seeks to explain why certain nations grow faster than others.

For their part, Gutierrez et al. (2004) argue that Solow modified the growth approach proposed by Harrod, who focused on demand and the existence of economic imbalances. In contrast, the Solow–Swan model focuses on supply, given that it assumes perfect markets and the premise that saving equals investment, thus complying with Say's Law. On the other hand, although it is known as the neoclassical model, many authors classify it within the classical–Keynesian synthesis. However, it has been called neoclassical simply to oppose Harrod's Keynesian model.

Given its relevance in economic growth theory, the present study will use the Solow-Swan model as a framework of reference.

Empirical Aspects

This section addresses the variables, dimensions, and main economic theories that support the analysis of growth and development in the studied context.

First, the independent variable is public expenditure, an economic indicator used by the state to improve the quality of services offered. Its relevance lies in its capacity to reduce economic inequalities, increase labor productivity, and correct failures in income distribution (Acuña et al., 2021).

Within this variable, three fundamental dimensions are distinguished. The first is science and technology expenditure (S&T), whose purpose is is to promote skills development within communities, providing real access to resources that promote socioeconomic autonomy, and offering alternatives to solve the most urgent challenges facing the population (Lara & Rojo, 2021).

The second dimension is education expenditure, which refers to the financial resources allocated by the government to this sector. It includes a wide range of initiatives and disbursements necessary to ensure a quality educational system, from an initial stage to post-secondary education (Jungo, 2024).

Finally, the third dimension is spending on scientific innovation. This is geared toward developing new knowledge through methodical and systematic procedures based on experimentation and observation. Its purpose is to verify hypotheses, explain natural, social, or technical phenomena, and produce new inventions in various areas of society. Thus, this spending contributes to both scientific and technological advancement (Ahmed et al., 2024).

On the other hand, the dependent variable corresponds to economic growth, which is understood as the increase in the proportion of labor and in the value of goods and services that an economy generates during a predetermined period. Now, generally, this growth is expressed as a percentage of the variation in GDP (Donayre et al. 2020, as cited in Granoble et al., 2022).

In this regard, one of the key dimensions of economic growth is gross domestic product (GDP), a parameter that reflects the total amount of final goods and services created in a country or continent over an evaluated period. It is worth mentioning that only final goods and services are considered, given that their price already incorporates the value of the inputs used in their production (Peruvian Institute of Economics [IPE], 2021).

Related Studies

This section presents an evaluation of the literature related to the research objective. In their article developed in Asia, the authors Nguyen and Bui (2022) evaluated how corruption control influences the link between public expenditure and GDP growth in 16 emerging Asian markets between 2002 and 2019. Their findings show that public expenditure has a negative impact on corruption control and economic growth, with an estimated value of -0.61 ($p = 0.01$). They concluded that effective corruption control is essential to increase the benefits of public expenditure.

For their part, Ahmed et al. (2024) investigated the relationship between **democracy and innovation** in 61 developing countries during the period 2013-2020, using data from the Global Innovation Index. They did not find a statistically significant relationship between them, suggesting that factors other than the level of democracy might influence the innovative capacity of these countries.

Jungo (2024) studied how institutions, financial inclusion, military spending, and education spending impact GDP growth in 61 developing countries between 2009 and 2020. The results indicated that low institutional quality, poor financial inclusion, and increased military spending are obstacles to economic growth, whereas spending on capital formation and education contribute positively to economic development.

In Portugal, Afonso and Rodrigues (2023) studied the effect of government investment in construction and R&D in 40 advanced and emerging countries between 1995 and 2019. They found that public investment has a significantly greater impact on economic growth than private investment, with multipliers of 2.29 for emerging economies and 0.87 for advanced economies.

In Russia, Dvoretskaya et al. (2023) analyzed the innovative development of education in the context of economic modernization between 2022 and 2031. They highlighted an increase of 982.51% in equipment modernization and a growth of 10,269.44% in research processes, both necessary to place Russian universities in the first place in the QS ranking. In the medium term, they suggested that 90% of the equipment in universities should be less than 5 years old, which would improve their position in said ranking by 6.17%.

Qazi and Ammad (2020) in Pakistan, evaluated the efficiency of state investment in sectors such as infrastructure, energy, health, and education. They found that, in 49 of the cases analyzed, the investment had a significant upward effect on production, while in 21 cases negative effects were observed. Likewise, in 34 cases an increase in employment was recorded and in 36 cases a substitution of labor was evidenced.

Soete et al. (2022) analyzed the impact of public R&D investment on total factor productivity (TFP) in 17 OECD countries between 1975 and 2014. They found that public R&D has a clearly favorable effect on the increase of TFP in almost all the countries analyzed, with a strong complementarity between public and private R&D in several cases.

Granoble et al. (2022) identified how GDP growth impacts the social progress index in Ecuador during 2015-2020, finding an association between both variables. This confirms, that actions were taken in Ecuador to solve fundamental problems such as social inequality, poverty, and other social problems.

Zhong (2021) investigated the connection between science and technology expenditure and GDP growth in Guangdong Province, China. He concluded that both government financial investment in S&T and R&D investment have an important impact on economic development, with a clear positive relationship between them.

Lara and Rojo (2021) analyzed the trend and growth of science and technology (S&T) in Ecuador. They found that during the period 2012-2014, there were inconsistencies in investment expenditure, which produced uncertainty about budget management in this area. Although there was a 23% growth in science and technology and an increase in academics, the impact on GDP was only 1%.

Velásquez (2025) evaluated the factors that influence digital adoption in micro and small enterprises (MSEs) after the pandemic He indicated that high levels of sustainability and the adoption of new technologies lead to economic growth, highlighting that digitalization is key to economic development.

Okoye et al. (2022) conducted a comparative analysis of global investment in education and science, technology, and innovation (STI) between 2015 and 2020. They found highly significant differences ($p \leq 0.05$) in investment in education and STI according to GDP and the number of academics, suggesting that the level of investment varies according to the region and its demographic characteristics.

Similarly, Niken et al. (2022) analyzed income disparities in Indonesia, concluding that investment, education, and technology have limited effects on reducing these inequalities. However, they identified significant differences between regions, especially compared to the province of DKI Jakarta.

On the other hand, Artige and Cavenaile (2023) explored the effect of public education expenditure on GDP growth and income inequality in the United States. They found that greater investment in education does not always reduce inequality, as its effectiveness depends on how it is financed and the socioeconomic conditions of each state.

In South America, Gómez et al. (2023) investigated the impact of state expenditure on education, health, and R&D in South America between 1995 and 2018. Indicating that only expenditure allocated to the education sector has a significant upward impact on GDP growth, highlighting the need to rethink the allocation of public resources to optimize their impact.

Along these lines, Arévalo et al. (2024) analyzed the consecutive factors of innovation and its impact on the economic growth of Peru during the period 2021 and its projection to 2030. Their results indicate that investment allocated to science and technology positively impacts the sustainable growth of Peru, that is, GDP.

Villela and Paredes (2022) examined state expenditure on education and human capital in Honduras during 1990 and 2020. They did not find a direct connection between education expenditure and economic development, suggesting that human resources are not being adequately used to boost development.

Quispe et al. (2024) evaluated the technical efficiency of education expenditure in Peru between 2016 and 2022, concluding that, although this investment positively affects the learning success of basic courses, its effect was not significant.

Paredes (2024) analyzed the effect of public expenditure allocated to the educational field on GDP growth in southern Peruvian regions during 2003 and 2021. His results indicate that expenditure on human capital and education generates a positive effect on GDP, given that a 1% rise in educational expenditure increases economic growth by 0.12%.

Peña (2021) investigated the statistical relationship between state expenditure and economic growth in Venezuela during 1950 and 2017. Confirming that state expenditure significantly influences economic production in the long term, which highlights its potential as a key tool to boost internal demand and promote development.

Khanchaoui et al. (2020) evaluated the impact of public expenditure, specifically the impact of physical capital development on the inclusive growth of Morocco's GDP, concluding that, in future stages, such expenditure positively impacts economic growth and that governmental action on human capital issues is effective in stimulating economic growth.

In Mexico, Camargo and González (2022) analyzed the connection between state expenditure and economic growth. They found that, in general, economic growth drives the rise in state expenditure (Wagner's Law), although in certain contexts public expenditure can also act as an engine of growth (Keynesian hypothesis).

Aguilar and Mahecha (2022) investigated labor informality on the Colombia-Venezuela border between 2011 and 2017 highlighting that factors such as fiscal income and educational coverage reduce informality, although they did not find a direct relationship between economic growth and informality at a general level.

Finally, Sánchez (2020) evaluated the viability of state debt in the state of Mexico, concluding that an increase in public investment leads to generating economic growth without compromising fiscal stability, as long as the productive use of resources is managed and prioritized.

METHODOLOGY

Database

In this study, the EViews software is used to evaluate 16 Latin American countries, excluding Venezuela and Cuba. This tool allowed for efficient processing, visualization, and modeling of the data, which enabled better interpretation of the results and clearer conclusions about what was happening in the data.

The methodology adopted a quantitative approach, based on collecting and examining numerical information with the aim of evaluating the proposed hypothesis, allowing for the detection of trends and the establishment of precise inferences (Hernandez & Mendoza, 2018). For this, a panel data structure corresponding to the period 1990–2022 was used, which was processed and analyzed using econometric models and statistical tests executed in the EViews software. In terms of the research level, it was analytical, as it not only described the characteristics of the analyzed variables but also evaluated the degree of association between them and sought to determine the causal impact of one variable on another (Hernandez & Mendoza, 2018).

On the other hand, according to Hernández and Mendoza (2018), the population is the total number of units that share certain criteria or attributes previously established in the study. The population under study was the macroeconomic indicators of the variables: public expenditure on S&T, Education and scientific Innovation (Number of patents) and economic growth (millions of soles).

Meanwhile, according to Hernández and Mendoza (2018), the sample corresponds to a part of the total population chosen with the purpose of obtaining information. It is essential that this sample be representative if the results are to be extended to the final set. The sample was compiled using data from the analysis period between 1990 and 2022.

To obtain the database, the document review method was applied, and the tool was a structured template to organize and examine secondary data, which are those that have been obtained by other academics. This involves the review of documents, national files, and physical or digital records (Hernandez & Mendoza, 2018, p. 291).

A second technique used was observation, developed using a structured instrument known as an observation form. This approach consists of data collection, i.e., systematically recording behaviors and situations in a validated and reliable manner. This ensures the adequate extraction of useful information for the research (Hernandez & Mendoza, 2018, p. 291).

Additionally, secondary sources were used to obtain quantitative data from different institutions. Among them: The National System of Science, Technology and Technological Innovation (SINACYT), the National Council of Science and Technology, the national census of CONCYTEC. Likewise, information from the World Bank related to investment in science and technology with the indicator (research and development), investment in education with the indicator (education expenditure) and investment in scientific innovation with the indicator (number of patent applications) was used. Finally, the Real GDP data, all of them in the period from 1990 to 2022.

METHOD

The statistical information was processed in the EViews software, where an econometric panel data model with fixed effects was applied, in order to control for unobservable heterogeneity and to capture the temporal variation of each variable. Subsequently, the data corresponding to the described periods was analyzed, in order to show the behavior of the variables and to verify if there is a direct or inverse relationship between them, with the objective of checking the general hypothesis and specific hypotheses.

The data processing was structured in three statistical levels. Regression and inferential statistics techniques were applied using EViews. First, a point estimation was performed for the Latin American countries, connecting the exogenous variables with the endogenous variable. Second, hypothesis tests were conducted to identify if the exogenous variables have a significant effect. For both procedures, the panel data model with fixed effects was applied, which allowed for evidencing the link between public expenditure on science, technology and research and the study variables.

In the following section, the econometric model used for the statistical analysis is presented, detailing its structure and justification in the context of the study. This model is used to capture the differences between countries that may influence the results.

Regarding Greene (2020), the fixed effects model allows us to capture the unobservable heterogeneity of each unit. Likewise, it is adequate when it is suspected that the individual characteristics are correlated with the exogenous variables, given that omission could generate biased estimators. The representation of the model can be expressed, in its classical form, as follows:

$$y_{it} = \alpha_i + X'_{it}\beta + \varepsilon_{it}, \qquad i = 1, \dots, n, \qquad t = 1, \dots, T$$

Where:

$$y_i = \begin{bmatrix} y_{i1} \\ y_{i2} \\ \vdots \\ y_{Tn} \end{bmatrix}$$

Represents the vector of the dependent variable

$$X_i = \begin{bmatrix} 1 & X_{i21} & X_{i31} & \cdots & X_{iT1} \\ 1 & X_{i22} & X_{i32} & \cdots & X_{iT2} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & X_{i2k} & X_{i3k} & \cdots & X_{iTk} \end{bmatrix}$$

Represents the vector of the independent variables.

$$\beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{bmatrix}$$

Represents the vector of the coefficients.

$$\varepsilon_i = \begin{bmatrix} \varepsilon_{i1} \\ \varepsilon_{i2} \\ \vdots \\ \varepsilon_{iT} \end{bmatrix}$$

Represents the vector of the idiosyncratic error.

In this sense, to estimate the model, the individual impact that is not observed in α_i, must be eliminated, this is done through the within transformation, also known as the "Within" transformation, which consists of subtracting the mean of each unit from all the exogenous variables, which gives us the following model:

$$\tilde{y}_{it} = \tilde{X}_{it}\beta + \tilde{\varepsilon}_{it}$$

Where:

$$\tilde{y}_{it} = \begin{bmatrix} y_{i1} - \bar{y}_i \\ y_{i2} - \bar{y}_i \\ \vdots \\ y_{Tn} - \bar{y}_i \end{bmatrix}$$

$$\tilde{X}_{it} = \begin{bmatrix} X_{i21} - \bar{X}_{i1} & X_{i31} - \bar{X}_{i1} & \cdots & X_{iT1} - \bar{X}_{i1} \\ X_{i22} - \bar{X}_{i2} & X_{i32} - \bar{X}_{i2} & \cdots & X_{iT2} - \bar{X}_{i2} \\ \vdots & \vdots & \ddots & \vdots \\ X_{i2k} - \bar{X}_{ik} & X_{i3k} - \bar{X}_{ik} & \cdots & X_{iTk} - \bar{X}_{ik} \end{bmatrix}$$

$$\tilde{\varepsilon}_{it} = \begin{bmatrix} \varepsilon_{i1} - \bar{\varepsilon}_i \\ \varepsilon_{i2} - \bar{\varepsilon}_i \\ \vdots \\ \varepsilon_{iT} - \bar{\varepsilon}_i \end{bmatrix}$$

Vector β contains the structural parameters of the estimated model, that is, they are the marginal effects of each exogenous variable on the endogenous variable $\tilde{y}_{it}$. This is how the individual heterogeneity α_i. is controlled. In addition, each β_k measures how much $\tilde{y}_{it}$, changes, in other words, when the variable X_{itk} increases by one unit, keeping the rest of the variables constant, i.e., under the *ceteris paribus* condition.

For the $\hat{\beta}$ estimators of the fixed effects model to be consistent and unbiased, they must meet the following assumptions: Stationarity, cointegration, multicollinearity and homoscedasticity.

Once the endogenous variable has been estimated, it takes the following matrix form:

$$\hat{y}_{it} = \bar{X}_i\hat{\beta}$$

And the statistical distribution of the endogenous variable is expressed as:

$$E(y_{it}) = \alpha_i + X'_{it}\beta$$
$$Var(y_{it}) = Var(\varepsilon_{it}) = \sigma^2$$

The general equation of a fixed effects regression model is:

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_n X_{nit} + \alpha_i + \varepsilon_{it}$$

Where:

Y_{it}: dependent variable

β_0: constant or independent term, indicates the value of Y when all X_i are zero.

$\beta_1, \beta_2, \ldots, \beta_n$: They are the regression parameters that quantify the expected change of each variable X_{it} over Y_{it} considering the other variables constant.

$X_{1it}, X_{2it}, \ldots, X_{nit}$: are the independent variables

α_i: is the unobservable heterogeneity

ε_{it}: is the disturbance term, specific shocks of *i* at *t*

Thus, the econometric model used in this research is presented below. This is built from the principles of fixed effects regression previously explained, which have been specifically adapted to the objectives of the study, in order to obtain more precise and relevant results.

Therefore, the fixed effects regression model to be estimated presents the following structure:

$$PBI_t = \phi_1 + \theta_i CyT_{it} + \beta_j E_{it} + \omega_z IC_{it} + \alpha_i + \varepsilon_{it}$$

Where:

$\theta_1, \beta_j, \omega_z$: coefficients that measure the impact of exogenous variables

PBI_{it}: Gross Domestic Product

CiT_{it}: Science and Technology

E_{it}: Education

IC_{it}: Scientific Innovation

α_i: Unobservable heterogeneity between countries

ε_{it}: Error

RESULTS

Correlation

Table 2. Correlation between Science and Technology (S&T), Innovation, Education, and Real GDP

	PBI real	CyT	Innovation	Education
PBI real	1.000000	0.767161	0.902156	0.223971
CyT	0.767161	1.000000	0.833229	0.463213
Innovation	0.902156	0.833229	1.000000	0.222194
Education	0.223971	0.463213	0.222194	1.000000

Source: Own elaboration

The correlation matrix reveals that investment in S&T, Education and Innovation are highly related to economic growth (Real GDP). Values close to 1 indicate a strong positive relationship between two variables; that is, when one increases, the other also tends to increase. Looking closely, S&T (0.7671) and Innovation (0.9021) show high correlations with Real GDP, indicating that the greater the investment, the greater the economic growth. Along this line, the low correlation with Education (0.2240) does not mean there is no relationship, given its long-term effect. Likewise, S&T and Education (0.4632) have a moderate correlation, which results in both being directly related to economic development. On the other hand, Innovation has a strong and positive correlation with GDP (0.9021), and with S&T (0.8332). However, it is lower for education (0.2221), indicating that innovation is directly associated with S&T and economic growth, while in terms of education, the association is weak.

The findings evidence the significant relationships between Real GDP, science and technology (S&T), education, and innovation, highlighting how these factors sustain and reinforce each other in a context of economic growth. The intense correlation between Real GDP and S&T expenditure indicates that allocating income to S&T is fundamental for Real GDP growth, and advancement in these areas is considered a primary engine for national growth and development. Along this line, the high correlation between Real GDP and Innovation emphasizes the importance that investing in innovation is essential for economic growth, given that policies are needed to boost the development of new technologies and innovative processes. Now, a moderate correlation between Education, S&T, and Real GDP indicates that the education sector not only drives GDP growth but also collaborates in scientific and technological development. Nevertheless, the minimal relationship between innovation and education suggests that, while education creates a favorable environment for innovation, it does not necessarily depend on it, but on other factors that influence its development. Collectively, the results achieved suggest that it is essential to create a comprehensive approach, given that it enables economic growth to be achieved; in other words, if we combine spending on science and technology, education, and innovation, real GDP will increase.

Econometric Analysis

In the stationarity analysis, the Dickey-Fuller test was used for the main variables of the model: Real GDP, S&T, Education and Innovation. Initially, the results for each variable indicated non-stationarity, with p-values greater than 0.05. Therefore, successive differences were calculated to verify if these series became stationary. After performing the first or second difference, depending on the case, the series became stationary, integrating to order one I (1), which allowed for further analysis with a cointegrated model.

For cointegration, the Engle-Granger test was applied, with a p-value of 0.01, which was essential to confirm the long-term presence of an equilibrium link between the variables. This result allowed to reject the null hypothesis that assumes the absence of cointegration, which implies that, despite the initial non-stationary trend, the series maintain a stable relationship over time, thus validating the cointegration of the series.

Regarding multicollinearity, a strong correlation was observed between S&T, Education, and Innovation. However, the Variance Inflation Factor (VIF) analysis showed values less than 10 for all variables, which confirms the absence of severe multicollinearity in the model and ensures the validity of the estimates.

Regarding homoscedasticity, the Breusch-Pagan test was applied, which yielded a p-value of 0.000, confirming heteroscedasticity, for which the method (vce(robust)) was used, which guarantees the robustness of the estimates of the panel data model with fixed effects.

In relation to normality and autocorrelation, although they were checked with the Shapiro-Wilk and Wooldridge tests, it is not convenient for the model to meet these assumptions, given that the Central Limit Theorem indicates that when there are many observations, the distribution tends to normalize. In this sense, the model is not affected by either autocorrelation or deviation from normality.

This set of tests ensures that the model meets the necessary assumptions for the precise interpretation of the results, increasing its robustness for the analysis of the relationships between Real GDP, S&T, Innovation, and Education.

Thus, the resulting model took the following form:

Table 3. Estimated Econometric Model

Dependent variable: Ln (GDP)				
	Estimators	Standard Error	t-Value	P-Value
Intercept	23.74993	0.149892	158.4469	0.0000
Ln (S&T)	0.064001	0.036429	1.756868	0.0795
Ln (Education)	0.821653	0.052852	15.54628	0.0000
Ln (Innovation)	0.071331	0.021454	3.324880	0.0009
Residual Standard Error	0.05332	R^2	0.969518	
R^2 Adjusted	0.96844	F Statistic	0.00000	

Source: Own elaboration

Thus, the econometric model was the following:

$$Ln(PBI)=23.74993+0.06400Ln(S\&T)+0.82165Ln(Education)+0.07133Ln(Innovation)$$

The fixed effects regression analysis performed to explain the logarithm of GDP (Ln GDP) based on the independent variables of the logarithm of Science and Technology (Ln S&T), Education (Ln Education) and

Innovation (Ln Innovation) shows statistically significant and robust results.

1. **Intercept:** The estimated value is 23.74993, which represents the value of Ln(GDP) when the other variables are zero. This parameter is highly significant, given its P-value of 0.0000.
2. **Ln (S&T):** The estimated coefficient of 0.06400 indicates that when all variables are kept constant, a 1% increase in S&T investment will lead to a 0.064% increase in GDP. However, its significance is marginal given that its P-value of 0.0795 is close to 0.08.
3. **Ln (Education):** With a coefficient of 0.82165, it indicates that education expenditure is the variable with the greatest impact on GDP. Thus, a 1% increase in education expenditure increases GDP by 0.82%, being highly significant with a P-value of 0.0000.
4. **Ln (Innovation):** The coefficient of 0.07133 indicates that a 1% increase in innovation expenditure will increase GDP by 0.071%, being highly significant with a P-value of 0.0009.
5. **R^2 and R^2 adjusted:** The model has an R^2 of 0.9695 and an adjusted R^2 of 0.9684, which suggests that 96.95% of the fluctuations in GDP are explained by the independent variables of the model, adjusting very well to the data.
6. **F Statistic:** The value of the F statistic is significant with a p-value of 0.00000, which shows that the model is globally significant from a statistical perspective.

In conclusion, the results indicate that allocating resources to the **Education and Innovation** sectors have a **positive and significant impact** on GDP, with **Education** being the variable with the greatest impact. The **S&T** variable also shows a positive effect, although marginally significant. The model is robust and largely explains the variation in GDP, which suggests that these variables are key determinants for economic growth in this context.

DISCUSSION

The model results identify a significant and positive correlation between the science and technology (S&T) variable and GDP growth. In particular, it is observed that a 1% increase in S&T expenditure leads to an increase of 0.064 percentage points in GDP. Based on this, all public policy decisions must focus on increasing S&T investment, as an increase in this leads to a significant impact on the country's economy. Along this line, government policies can be aligned to increase the S&T budget, promote public-private sector participation in these areas and promote scientific and technological education, thereby improving the economic benefits for these sectors and better positioning the country. Furthermore, this is significant with the findings by Zhong (2021) and Arévalo et al. (2024), who indicate that spending on S&T has a positive impact on GDP growth, with a clear link between them.

Therefore, the results evidence the idea that allocating expenditures to research and development (R&D) is positive for economic growth. However, science and technology expenditure is essential for economic growth, given that a rise in S&T will increase the level of GDP. Regarding the differences, expenditure depends on factors such as GDP, New Technologies, and the number of Academics (Zhong, 2021; Lara & Rojo, 2021; Velásquez, 2025; Okoye et al., 2022). Likewise, it is evidenced that public and private R&D expenditure has a positive effect on TFP, which is the growth of total factor productivity, which supports the idea that state policies improve economic efficiency. Along these lines, it is mentioned that adequate regulation on issues such as corruption is appropriate to increase the benefits of public expenditure (Nguyen & Bui, 2022; Granoble et al., 2022; Soete et al., 2022).

Regarding the impact of investment in educational expenditure, it is found that the area operates as a primary engine for economic growth, especially in countries that are in full economic development. in Latin America, education and physical capital expenditure have shown to have significant and positive impacts on GDP growth, indicating that a good allocation of resources towards education leads to a lasting impact on the economy (Jungo, 2024; Paredes, 2024; Quispe et al., 2024; Gómez et al., 2023).

Closing the discussion, the study results identify that innovation impacts economic growth significantly and positively, essentially in economies that are developing, which is currently Latin America. This result is consistent with Okoye et al. (2022), who found differences between science and technology (S&T) expenditure according to GDP and the number of academics, highlighting that the level of investment varies according to its region and demographic characteristics. For their part, Ahmed et al. (2024) did not find a significant relationship between democracy and innovation, indicating that the level of democracy does not influence the innovative capacity of consolidating countries. In South America, Gómez et al. (2023) mentioned that investing in innovation is an important role, but investing in the educational area has a greater effect on GDP growth, indicating that state policies must optimize their resource allocation to increase their impact. Along these lines, Khanchaoui et al. (2020), Peña (2021), and Camargo and González (2022) confirm that state expenditure positively impacts the development and growth of the economy. Therefore, the studies agree that innovation, when evaluated with an adequate allocation of resources in sectors such as education and S&T, has a significant effect on the economic growth of the region.

CONCLUSIONS

Regarding the conclusions, this study managed to identify that public expenditure for science and technology (S&T), education, and innovation tends to have a significant and positive effect on the GDP growth in different nations of Latin America, this in the evaluation period of 1990–2022. Now, by running the econometric model, with a 5% level of significance and a P-value of 0.000, considerable evidence was obtained to not accept the null hypothesis, suggesting that the exogenous variables (Science and Technology, Education, and Innovation) explain the endogenous variable (GDP) in Latin America.

Breaking down the study variables, Science and Technology (S&T) expenditure reflects a positive influence on economic growth with a P-value of 0.0795, which indicates a marginal significance close to 8%. Regarding Education, with a P-value of 0.0000, a statistically significant impact is observed as a result, which highlights its consolidation as one of the outstanding variables for GDP growth. On the other hand, Innovation expenditure, which is identified in new patents, with a P-value of 0.0009 has a positively significant effect.

Now, the identified results evidence the need to prioritize investment in specific and essential sectors, a task that falls to state policies, which not only encourage economic growth in the short term but also ensure constant economic development over time. Therefore, expenditure on S&T, Education, and Innovation is positioned as an outstanding factor in the structural transformation and strengthening of the competitiveness of Latin American economies.

Finally, the research suggests and proposes that further studies be developed and that include the factors used and other variables of state policy, such as infrastructure and governance, which may incentivize public expenditure to increase GDP growth. Along these lines, new research could incorporate more specific details about the regional effect and the effect of R&D expenditure on essential sectors of the economy

Limitations and Practical Implications

At the theoretical level, the limitation is moderate, since there are theoretical grounds that support the research, but it must be traced more precisely at the international level. The study period is delimited, from the year1990 to 2022, and the analysis focused on Latin America, excluding Venezuela and Cuba due to their macroeconomic instability and the lack of information on indicators.

The results suggest that public expenditure on science, technology, education, and innovation has a positive effect on the economic growth of Latin America between the period 1990–2022. In this sense, it remains important to prioritize and focus public investment on strategic projects, where economic diversification and increased productivity are promoted, as evidenced in countries with better development. Likewise, it is still important to strengthen human capital through technological and scientific education, as it constitutes an important mechanism for sustaining long-term growth.

Similarly, governments in the region must guide their policies towards a more efficient allocation of public expenditure, implementing monitoring and evaluation systems that ensure the impact of investments in science and education. Likewise, it is essential to provide incentives that enable collaboration between the public and private sectors as a strategy to expand innovative capacity and generate synergies that drive sustainable technological and economic development in the region.

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