Human capital, innovation and digitalization. Economic drivers in Latin America

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Abstract

This study examines the relationship between investment in higher education, Science, Technology and Innovation, the training of Specialized Human Capital, digitalization and economic growth in Latin America (2000-2019). Three fixed-effects panel data models linked to the Progressive Structural Change model are estimated. Investment in research and development (R&D) and tertiary education drives the formation of Specialized Human Capital. Additionally, researcher density and digitalization positively impact economic growth and the interaction between Specialized Human Capital and education reinforces this effect. Political isomorphism between higher education and innovation systems is essential. The study recommends collaborative governance with long-term policies that integrate education, innovation and digitization.

Keywords: human capital; innovation; technological change; panel data models.

1. INTRODUCTION

Training Specialized Human Capital (SHC)[1] has become a strategic focus for development in contexts of increasing global digitalization. Since the mid-20th century, specialized literature has systematically explored the links between Science, Technology and Innovation (STI), education and economic progress. Recently, there has been an emphasis on the challenges of digital transformation (Sabato and Botana, 1968; Vessuri, 1997; Albornoz, 2001; Casalet and Stezano, 2020b). Some studies highlight the interdependence between National Innovation Systems (NIS) and higher education as pillars for creating SHC, especially given the demands of the Fourth Industrial Revolution (ECLAC, 2018; Suárez *et al.*, 2020; Buendía García *et al.*, 2017). However, an analytical gap remains regarding the institutional mechanisms linking these systems in Latin America and their effects on regional economic dynamics. This raises the following questions: How does the number of researchers impact economic growth? How does investment in tertiary education and STI affect researcher training? Does investment in education and STI produce more researchers, which translates into greater economic growth?

The SHC evaluation prioritizes quantitative indicators, such as scientific output, postgraduate enrollment, investment in STI or patent registrations) as the basis for designing innovation policies (Edquist, 2019; Locatelli, 2018; Barrientes Seborga, 2020). While this approach allows for comparative diagnoses, it also has limitations in capturing the qualitative processes of interaction between educational, productive, and state actors. In developing economies, where NIS are often incipient and fragmented, recent studies highlight three critical dimensions: *1)* education as a public asset with positive externalities on economic growth (Espinoza, 2017; Fuentes, 2013); *2)* the training of researchers as a differentiating factor in R&D&i chains (ECLAC, 2018; Grundke *et al.*, 2018); and *3)* asymmetries between investment in STI, educational capital and national income levels (Ríos Bolívar and Marroquín Arreola, 2013; Suárez *et al.*, 2020). Despite these advances, regional literature has overlooked analyzing institutional isomorphisms between higher education and innovation. This analysis is key to understanding how joint investments in both systems enhance synergies in creating SHC.

This study proposes an analytical approach to examine the gap between SHC training, digitalization processes and economic development in Latin America. Based on the PSC model, the study suggests that investing in higher education and R&D increases the availability of highly qualified personnel in the medium term and generates synergies that strengthen countries' scientific and technological bases.

Additionally, it is argued that the density of researchers in STI and the institutional strengthening of the higher education system directly impact levels of digitalization, promoting processes of convergence and isomorphism between the education system and national innovation systems. In turn, this articulation contributes to economic growth, both directly and through positive interactions between human capital and the digital capabilities available in each country.

The findings partially support the proposed hypotheses: Models 1 and 3 show significant and consistent associations between investment in education, investment in R&D and SHC training and economic growth. However, model 2 shows heterogeneous patterns in the relationship between digitization and SHC, with effects that are not always significant or robust.

The results provide empirical evidence for contemporary debates on innovation policies in Latin America, particularly in three areas: *1)* the need to overcome fragmented approaches between education, STI and digitalization through comprehensive strategies for progressive structural change; *2)* the importance of strengthening collaborative governance mechanisms and political isomorphism to align institutional incentives between higher education systems and national innovation systems; *3)* the methodological challenges of measuring synergies between systems highlight the relevance of using panel data models with temporal interactions to capture deferred and contextually conditioned effects.

The article is organized into five sections following this introduction. First, the Progressive Structural Change (PSC) model is reviewed as a theoretical basis for understanding the region. The analytical framework is developed in the next section. The methodology and data sources are detailed next. The results are presented in the following section and compared with previous studies. The final section discusses implications for public policy design in the region.

2. PROGRESSIVE STRUCTURAL CHANGE MODEL

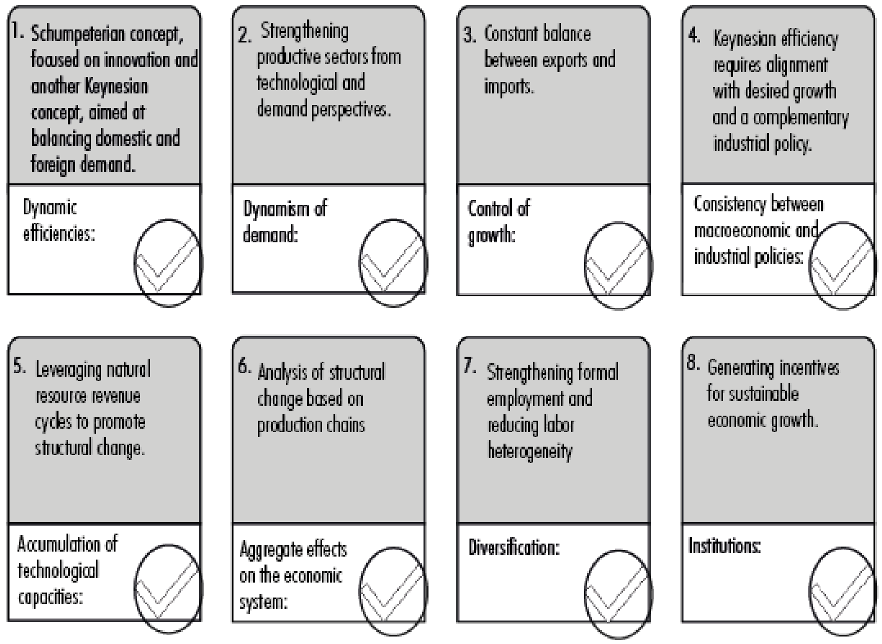
Since the beginning of the 21st century, digitalization has become more relevant in Latin America, indicating a shift in the region's productive structure (Casalet and Stezano, 2020a). Digitalization is defined as the integration of digital technologies into Industry 4.0 processes in industry and manufacturing (Yoguel, 2020; Carmona *et al.*, 2020; Casalet, 2018). However, the region faces several challenges, including: a low rate of digitalization in production processes (Casalet and Stezano, 2020a and b; ECLAC, 2018); the impact of the economic crisis exacerbated by the Covid-19 pandemic, which exacerbated pre-existing inequalities (Stezano, 2021; ECLAC, 2020; OECD *et al.*, 2020) and the need to strengthen SHC training to facilitate the digital transition in the productive structure (ECLAC, 2018; Grundke *et al.*, 2018; Katz, 2018). This last aspect is central to this paper and requires an analytical framework that allows for the analysis of the multidimensionality of economic growth and its relationship with SHC training.

The PSC model (Stezano, 2021; ECLAC, 2012 and 2016) is an ideal theoretical framework for this analysis because it explains how economies evolve through human capital and demand. Throughout the 20th century, the region implemented various development models, but the PSC model stands out for its consideration of structural inequalities (Stezano, 2021). According to the ECLAC (2012), the PSC model is based on the principles shown in Figure 1.

Despite the potential of the PSC model, national policies have made little effort to promote the comprehensive implementation of structural change. In this regard, Stezano (2021) presents a revised synthesis of the PSC model that incorporates six key dimensions: 1) social equity; 2) transitioning jobs to high-productivity sectors; 3) environmental sustainability; 4) productive diversification; 5) growth-oriented macroeconomic policies; and 6) industrial policies for capacity building.

In this context, digitalization, SHC training and the accumulation of technological capabilities are interdependent dimensions of progressive structural change strategies. While the PSC model emphasizes the need for comprehensive policies to boost dynamic productive sectors and reduce inequalities, the literature on SHC provides key insights into how investment in higher education and R&D translates into effective innovation capabilities.

Figure 1. Principle of the PSC Model



Source: Prepared by the author based on Stezano (2021).

However, simply increasing the number of university graduates or public investment in STI does not, in itself, guarantee efficient coordination between education, science and productive development. Therefore, it is essential to incorporate an approach that considers the structural relationships between higher education systems and national innovation systems. This perspective highlights the concept of political isomorphism, which is defined as the degree of correspondence and alignment between these systems, as well as the existence of collaborative governance mechanisms that enable functional integration without loss of institutional autonomy. Based on this theoretical framework, the objective of this study is to analyze the impact of investments in higher education and STI, together with the level of digitalization, on SHC training and economic development, taking into account the structural and institutional characteristics of each Latin American country.

3. SPECIALIZED HUMAN CAPITAL, POLITICAL ISOMORPHISM AND GOVERNANCE

The study of SHC in developing countries has been the subject of analysis in various research projects, particularly regarding its relationship with investment in education, STI (Arias Ortiz *et al.*, 2020; Barrientes Seborga, 2020; González and Jiménez, 2014; Lucía *et al.*, 2012; Rivas Tovar, 2004; Sánchez Luján and Hinojosa Luján, 2020; Suárez *et al.*, 2020). In this regard, Ríos Bolívar and Marroquín Arreola (2013) highlight that, in the case of Mexico, economic incentives aimed at promoting investment in R&D have a positive and significant effect on economic growth. This finding reinforces the importance of policies aimed at strengthening national innovation systems.

Suárez *et al.* (2020) delve deeper into the analysis by examining investment in ICT and SHC in a sample of 72 countries. Their results show that, while investment in R&D positively impacts GDP growth in both high- and middle-income countries, specific investment in SHC is significant only in middle-income countries. This observation coincides with the conclusions of Barrientes Seborga (2020), who evaluates the role of education as a public asset in the Andean region and argues that there is a direct causal relationship between educational investment and economic growth.

Meanwhile, Locatelli (2018) questions the conceptualization of education as a public asset. He points out that, although political discourse presents education as such, its definition is ambiguous in practice due to the intersection between the public and private spheres in its implementation. This debate is significant considering Figueroa-García’s (2014) argument that postgraduate research training programs in Latin America are recent and face challenges related to consolidating robust and sustainable academic ecosystems. Mayta-Tristán (2010) also addresses this issue with respect to the role of scientific associations in the region.

The literature reviewed agrees on the need to develop an academic and scientific ecosystem that promotes SHC training and overcomes governance, institutional and democratization challenges in higher education and research (Arias Ortiz *et al.*, 2020; Barrientes Seborga, 2020; Suárez *et al.*, 2020). This approach is linked to the importance of strengthening knowledge management in universities and research centers (Romo-González *et al.*, 2012). Knowledge management is understood as a process that aims to increase human capital and improve institutional capacities for innovation and social development.

Finally, digitalization presents a structural challenge and an opportunity to promote economic development through SHC training. As Grundke *et al.* (2018) and Katz (2018) argue, public policies prioritizing investment in scientific, technological and digital skills training are crucial for overcoming existing gaps in economic and social development.

The relationship between investment in R&D or higher education and the performance of NIS has been widely documented in Latin America (Arias Ortiz *et al.*, 2020; Barrientes Seborga, 2020; Buendía García *et al.*, 2017; Estudios y Documentos de Política Científica en ALC, 2010; Garza and Espinosa, 2015; Ríos Bolívar and Marroquín Arreola, 2013; Senclier de Cortez, 2017; Suárez *et al.*, 2020). However, there is a consensus that the challenge lies in how to operationalize and specifically measure SHC training within NIS.

Traditional approaches have limited their analysis to the number of university graduates as an indicator of SHC training (Buendía García *et al.*, 2017; Garza and Espinosa, 2015; Senclier de Cortez, 2017). This approach is insufficient because it does not capture the capacity of the state to provide resources or the effective impact of such training on the performance of NIS. Furthermore, these analyses tend to consider investment in higher education only as an input, rather than as a process or as a specific outcome in terms of active researchers.

Given these limitations, this study uses the PSC model as its basis and integrates the concept of political isomorphism to understand the relationships between higher education and STI. Political isomorphism is understood as the structural and functional correspondence between two interacting systems that maintain autonomy while generating institutional arrangements and collaborative governance mechanisms (Casalet, 2018 and 2020; Locatelli, 2018). This perspective is especially relevant in the Latin American context, where the coevolution between both systems has intensified since the beginning of the 21st century (Romo-González *et al.*, 2012).

From this perspective, SHC training is conceptualized in two dimensions:

- Educational: Universities train professionals to solve local problems through innovation processes (Gregorutti, 2014). This dimension incorporates the idea that training is a social and relational process, consistent with the sociological perspective of Kuhn's scientific paradigms (1971).
- Economic: SHC training generates positive externalities such as aligning the labor market with graduates (Arias Ortiz *et al.*, 2020), promoting technology companies (Grilli and Murtinu, 2018; Wang, 2017) and the strengthening companies' knowledge absorption capacities (Lenihan *et al.*, 2019).

Both dimensions reinforce the hypothesis of political isomorphism between higher education and NIS, providing a framework for analysis that includes collaborative governance mechanisms based on networks of stakeholders, formal and informal agreements, and institutional innovation strategies (Casalet, 2020).

Methodologically, this study employs panel data models with individual fixed effects and temporal interactions to analyze the impact of public investment in higher education and in STI activities on economic growth and SHC training. Variables capturing both inputs (e.g., R&D spending and tertiary education spending) and outputs (e.g., number of researchers per million inhabitants) are selected, overcoming the limitations of previous studies that focused only on aggregate indicators. This strategy addresses the need to evaluate the interactive effects among investment, SHC training and economic development using a collaborative governance and structural analysis approach.

In short, the central argument is that the density of STI researchers is a key factor associated with a country's economic development because it reflects the accumulation of SHC. However, this relationship does not operate automatically: it depends on the existence of collaborative governance schemes, which are understood as the degree of alignment and interaction (or political isomorphism) between national innovation and higher education systems. In contexts where this isomorphism is weak, technological capabilities will likely be limited, which will restrict the impact of human capital on economic growth. Conversely, countries where this articulation is strong have a greater capacity to translate STI efforts into productive processes that contribute to economic development.

Similarly, a critical component of contemporary technological capabilities is the level of digitalization, which is defined as the adoption and widespread use of ICTs in society and the productive apparatus. However, in the Latin American context, digitalization has not always acted as a direct driver of economic development. Several studies (Casalet and Stezano, 2020a; Casalet, 2018 and 2020) warn that, in the absence of solid institutional frameworks and effective coordination between the education system, the innovation system and the productive sector, digitalization can have limited or even disparate effects. In such cases, digitalization functions more as a structural factor of backwardness than as a driver of growth. Therefore, this study incorporates its analysis as a modulating variable, whose effect is presumed to be conditioned by the specific institutional characteristics of each country.

It should be noted that these dynamics are modulated by the specific structural and institutional characteristics of each country, such as its governance model, economic structure or organizational culture surrounding science and technology. These characteristics tend to remain relatively constant over time.

4. MATERIALS AND METHODS

This analysis is based on the assumption that the dynamics between human capital training, digitalization and economic development in Latin America are mediated by structural factors and unobservable effects that are unique to each country. This justifies the use of fixed-effects models (Wooldridge, 2010; Nickell, 1981) to control for unobserved heterogeneities and more accurately estimate the impact of explanatory variables on economic growth.

From this perspective, a sustained increase in public investment in higher education and R&D is considered to have structurally impacted the expansion of SHC, as measured by the density of researchers per million inhabitants. This relationship largely depends on institutional capacities for coordination between higher education systems and national innovation systems.

Similarly, this human capital density is expected to positively impact countries' levels of digitalization. However, this effect may be sensitive in the short term, revealing certain structural limitations related to technology absorption and weak coordination between the education and production sectors.

Finally, it is suggested that both researcher density and investment in tertiary education contribute significantly to economic growth, and that their interaction enhances this effect, reflecting the synergies typical of collaborative governance between educational, scientific and productive agents. Digitalization, for its part, acts as a complementary factor to human capital and has a positive impact on economic performance, though no significant interaction effects are evident.

To test these hypotheses, a one-way (individual) fixed effects model was used for the first and third hypotheses and a two-way model was used for the second. This approach was based on applying F-tests for individual or temporary effects (Wooldridge, 2010).

To capture the deferred nature of certain structural processes, time lags were incorporated into key variables such as investment in R&D and tertiary education. This decision was based on two main reasons: first, theoretically, the effects of these investments on SHC training and their subsequent impact on the economy are not immediate but rather tend to manifest themselves in the short- and medium-term (one to five years) according to the literature on structural change (ECLAC, 2018). Second, from an econometric perspective, the use of lags mitigates potential problems of endogeneity and simultaneity by reducing the risk that the explanatory variables are correlated with the contemporary error term. In this respect, lags allow for a more accurate estimation of the cumulative causal effects over time, which is particularly relevant in studies of economic development in contexts of slow institutional and technological change.

The database is a panel database and data from the World Bank (2025) updated as of July 1, 2025, was used. The sample includes observations from 21 Latin American countries during the period from 1999 to 2019: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominica, Ecuador, Guatemala, Haiti, Honduras, Mexico, Panama, Paraguay, Peru, Puerto Rico, Trinidad and Tobago, Uruguay, and Venezuela.

As for the econometric models, the first one aimed to estimate the effect of investment in R&D and tertiary education on SHC training, operationalized by the number of researchers engaged in R&D per million inhabitants (IDIDXM). This estimate is based on the PSC model approach, which highlights the accumulation of technological capabilities and SHC training as key dimensions for sustainable economic development in Latin America.

- Dependent variable: Researchers engaged in R&D per million inhabitants.
- Treatment variables: R&D expenditure as a percentage of GDP; public expenditure on tertiary education per student as a percentage of GDP per capita, adjusted using intra-country de-mean to capture only the variation within each observational unit.
- Control variables: Exports of high-tech products; inflation, consumer prices (annual %); value added by industry as a percentage of GDP.

The econometric formulation corresponds to an individual fixed effects model:

$$\begin{aligned} IDIDxM_{it} = {} & \beta^0 + \beta^1 ExpenditureIDxGDP_{it} + \beta^2 ExpenditurexStudent_{GDP_{it}} \\ & + \beta^3 EPAT_{it} + \beta^4 Inflation_{annual_{it}} \\ & + \beta^5 AddedValueIndustry_{it} + \mu_i + \varepsilon_{it} \end{aligned}$$

Where μ_i represents fixed effects by country and ε_{it} represents the idiosyncratic error term.

The second model evaluated the effect that researcher density, together with spending on tertiary education and R&D, has on the level of digitalization in Latin American countries, operationalized by the percentage of individuals who use the internet. This relationship is articulated from the perspective of political isomorphism proposed in the theoretical framework, considering that a robust academic and scientific ecosystem should contribute to increasing technological absorption capacity, reflected in higher levels of digitalization.

- Dependent variable: percentage of individuals who use the internet.
- Treatment variables: researchers engaged in R&D per million inhabitants; public expenditure on tertiary education as a percentage of GDP per capita.
- Control variables: exports of goods and services as a percentage of GDP; inflation, consumer prices (annual %); value added by industry as a percentage of GDP.

The econometric formulation is specified as:

$$
\begin{aligned}
Internet\ users_{it} = \beta^0 + \beta^1 IDIDxM_{it} \\
&+ \beta^2 ExpenditurexStudent_{GDP_{it}} \\
&+ \beta^3 Export\ of\ AandS.gdp_{it} \\
&+ \beta^4 Inflation_{annual_{it}} \\
&+ \beta^5 added\ value\ industry_{it} \\
&+ \mu_i + \lambda_t + \varepsilon_{it}
\end{aligned}
$$

Being a two-way fixed effects model (individual and temporal), given the nature of the phenomenon analyzed and the empirical evidence observed in the F tests for significant effects.

The third model estimated the combined impact of researcher density, the level of digitalization and public investment in tertiary education on economic development, measured by the natural logarithm of GDP per capita. In accordance with the theoretical framework, this model allows us to test the political isomorphism hypothesis and evaluate how these dimensions interact to shape PSC trajectories in Latin American countries.

- Dependent variable: natural logarithm of GDP per capita.
- Treatment variables: public spending on tertiary education as a percentage of GDP per capita; researchers engaged in R&D per million inhabitants; interaction between spending per student and researchers per million to capture modulating effects; percentage of individuals who use the internet.
- Control variables: exports of goods and services as a percentage of GDP; inflation, consumer prices (annual %); value added by industry as a percentage of GDP.

The econometric formulation of the model is expressed as follows:

$$
\begin{aligned}
\mathrm{Log}(GDP\ per\ capita_{it}) = \beta^0 + \beta^1 ExpenditurexStudent_{GDP_{it}} \\
&+ \beta^2 IDIDxM_{it} + \beta^3 ExpenditurexStudent_{GDP} \\
&* IDIDxM_{it} + \beta^4 Internet\ users_{it} \\
&+ \beta_x Controls_{it} + \mu_i + \varepsilon_{it}
\end{aligned}
$$

Individual fixed effects model which, according to the empirical results obtained, shows a significant effect of the interaction between digitalization and SHC on economic development, conditioned by the structural characteristics of each country.

RStudio programming environment version 2025.05.0 was used for the data analysis. To determine the model used, two-way models were run, both temporal and individual. The models were compared using an F-test (Wooldridge, 2010), which contrasted the joint inclusion of country effects with those of year, in this case justifying the two-way model for model two as the specification that best captures the heterogeneity of the panel.

Finally, to ensure the robustness of the results obtained and verify the consistency of the estimators, the coefTest function was applied. This function estimates robust standard errors in the presence of heteroscedasticity and autocorrelation in panel data models (Wooldridge, 2010), thus ensuring that the reported results are not the product of restrictive assumptions. The specialized *plm* and *sandwich* libraries, widely recognized in applied econometric literature, were used for the adjustment and estimation of the models.

Additionally, all necessary methodological considerations were taken into account to preserve the internal validity and interpretive consistency of the models: *(i)* country-specific fixed effects were controlled to reduce bias due to omitted variables; *(ii)* the selection criteria for treatment and control variables were exhaustively documented, taking into account both theoretical and empirical criteria. These methodological precautions seek to ensure that the reported coefficients can be consistently interpreted and that the conclusions drawn are based on statistically sound foundations.

5. RESULTS

The results allow us to empirically validate some of the hypotheses formulated within the PSC model, articulating the relationship between investment in science and technology, SHC training, digitalization and economic growth in Latin America (see Table 1).

First, Models 1 and its variants with lags (one, three and five years) confirm that R&D spending has a positive and statistically significant effect on the number of researchers per million inhabitants, especially in the immediate lag (Model 1) and at one year (Model 1.1). These findings align with the PSC principle of accumulation of technological capabilities and reinforce the idea that a policy of sustained public investment in STI is crucial to strengthen the SHC. However, this effect weakens with the three- and five-year lags, which could be interpreted as evidence of a lack of robust collaborative governance mechanisms to sustain this impact over time, in line with the findings of Casalet (2020) and Locatelli (2018). Second, Models 2, 2.1, 2.3 and 2.5, which link researchers per million to the level of digitalization measured by the number of internet users, show more heterogeneous results. While Model 2 and Model 2.5 demonstrate significant effects of researchers per million on internet users, Models 2.1 and 2.3 do not achieve statistical significance. This behavior reinforces the thesis that digitalization acts as a modulating dimension that does not operate linearly. The literature reviewed warns that, in the absence of solid institutional structures, the SHC may not be fully integrated into productive digitalization processes, thereby limiting its economic impact (Grundke *et al.*, 2018; Katz, 2018). The significant negative sign for exports of goods and services in Model 2.5 also suggests structural tensions associated with the international integration of Latin American economies, showing that greater economic openness does not always translate into higher levels of digitalization.

Finally, Models 3, 3.1, 3.3, and 3.5 allow us to observe the combined effects of researchers per million, expenditure per student, internet users and the interaction between researchers per million and expenditure per student on economic growth, as measured by the natural logarithm of GDP per capita. The results show that the number of researchers per million people, expenditure per student and Internet users maintain statistically significant and consistent effects in all models. Notably, the interaction between researchers per million and expenditure per student has a positive and significant effect in all specifications, reinforcing the argument of political isomorphism: the structural and functional correspondence between the higher education system and the innovation system contributes to economic growth in a coordinated manner. The evidence suggests that investing in SHC or tertiary education in isolation is insufficient; combining both dimensions, as expressed in the interactive effect, enhances results. These findings coincide with those of Suárez *et al.* (2020) and Barrientes Seborga (2020) in respect to the need to strengthen collaborative governance mechanisms that effectively align both systems.

The robust results presented in Table 2 partially confirm the hypotheses put forward by the PSC model and political isomorphism theory and provide differentiated empirical evidence according to the modeled relationship: SHC training, digitalization, and economic impact.

First, the R 1 models linking investment in higher education and STI to the formation of SHC (researchers per million) show a positive, statistically significant effect of R&D expenditure (expenditure per student) in model 1. In model 1.1 (one-year lag), in addition to R&D, expenditure on tertiary education (expenditure per student) is also significant. This relationship disappears or loses significance at longer lags, which is consistent with literature pointing out that the effect of STI investments on SHC training is sensitive to the institutional context and the presence of collaborative governance mechanisms (Suárez *et al.*, 2020; Casalet, 2020). Notably, the component regarding industry participation in GDP is significant in model R 1, with a negative sign, which reinforces the idea of structural tensions between the traditional productive structure and emerging technological capabilities.

Regarding the R 2 models, which explore the relationship between SHC and digitalization, it can be seen that researchers per million have a positive and significant effect on the R 2 and 2.5 models, while in the intermediate lags the effect is diluted. This could be interpreted as evidence that SHC training contributes to digitalization, although this contribution depends on institutional synchronization and short-term policies, as suggested by the PSC model in its principles on macroeconomic and industrial coherence. Furthermore, expenditure per student is only marginally significant in the R 2.5 model, which would indicate that public spending on tertiary education has a limited effect if it is not accompanied by more robust governance schemes.

Table 1. Results of models 1, 2, and 3

Variable	*Model 1*			*Model 1.1*			*Model 1.3*			*Model 1.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
R&D expenditure	748.4	245.84	0.004 **	682.2	294.61	0.027 *	-142.31	369.5	0.7	-1039.51	490.77	0.056
Expenditure per student	5.03	3.45	0.15	11.45	4.09	0.008 **	0.39	4.52	0.93	-4.998	5.51	0.38
High-tech exports	-4.07	2.12	0.062	-2.22	2.22	0.33	3.93	7.57	0.61	-11.88	9.76	0.247
Inflation	4.72	5.34	0.38	4.09	5.21	0.44	1.197	7.15	0.87	-10.4	4.86	0.054
Value added of the industry	-9.42	3.99	0.023 *	-4.9	4.19	0.25	-9.06	6.32	0.17	-14.91	9.077	0.126
Variable	*Model 2*			*Model 2.1*			*Model 2.3*			*Model 2.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
Researchers per million inhabitants	0.015	0.007	0.034*	0.009	0.007	0.167	0.003	0.007	0.683	-0.011	0.006	0.109
Expenditure per student	-0.051	0.099	0.605	0.033	0.096	0.730	0.101	0.094	0.292	0.104	0.098	0.295
Export of goods and services	0.008	0.204	0.969	-0.251	0.197	0.209	-0.177	0.199	0.378	-0.603	0.233	0.014*
Inflation	-0.037	0.236	0.877	0.124	0.229	0.590	-0.129	0.226	0.571	0.070	0.289	0.811
Industry, value added (% of GDP)	0.241	0.526	0.649	0.478	0.510	0.354	0.249	0.516	0.632	0.477	0.536	0.380
Variable	*Model 3*			*Model 3.1*			*Model 3.3*			*Model 3.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
Researchers per million inhabitants	-0.0011	0.0003	0.0019**	-0.0013	0.0003	0.0007***	-0.001	0.0004	0.001**	-0.002	0.0004	0.0001***
Expenditure per student	-0.0120	0.0034	0.0008***	-0.0136	0.0035	0.0003***	-0.014	0.0040	0.001**	-0.015	0.0037	0.0002***
Internet users	0.0078	0.0010	6.54E-11***	0.0081	0.0010	9.20E11***	0.007	0.0012	1.19E-7***	0.007	0.0012	4.90E-07***
Export of goods and services	-0.0057	0.0034	0.09	-0.0048	0.0035	0.18	-0.004	0.0041	0.36	-0.003	0.0045	0.464
Inflation	0.0100	0.0040	0.015*	0.0089	0.0041	0.03*	0.011	0.0047	0.023*	0.009	0.0049	0.075.
Industry, value added (% of GDP)	0.0199	0.0070	0.006**	0.0212	0.0072	0.005**	0.019	0.0084	0.03*	0.012	0.0085	0.161
Interaction	4.19E-05	1.06E-05	0.00021***	4.73E-05	1.10E-05	6.50E5***	4.72E-05	1.25E-05	0.0004***	4.77E-05	1.17E-05	0.0002***

Notes: signif. Codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '; 1

Source: prepared by the author.

Table 2. Robust results for Models 1, 2, and 3

Variable	*Model R 1*			*Model R 1.1*			*Model R 1.3*			*Model R 1.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
R&D expenditure	748.4	277.5	0.01*	682.2	233.84	0.006**	-142.31	501.41	0.78	-1039.51	728.05	0.18
Expenditure per student	5.03	3.26	0.13	11.45	3.04	0.0006***	0.39	4.37	0.93	-4.998	5.53	0.384
High-tech exports	-4.07	2.27	0.08	-2.22	1.83	0.23	3.93	12.31	0.75	-11.88	11.82	0.335
Inflation	4.72	3.12	0.139	4.09	3.11	0.197	1.197	3.71	0.75	-10.4	2.25	0.0006***
Value added of the industry	-9.42	1.27	6.192e-09 ***	-4.9	2.2	0.03*	-9.06	8.08	0.27	-14.91	8.47	0.104
Variable	*Model R 2*			*Model R 2.1*			*Model R 2.3*			*Model R 2.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
Researchers per million inhabitants	0.015	0.005	0.0069**	0.009	0.007	0.194	0.003	0.009	0.756	-0.011	0.004	0.013*
Expenditure per student	-0.051	0.112	0.649	0.033	0.090	0.715	0.101	0.108	0.357	0.104	0.051	0.05016
Export of goods and services	0.008	0.291	0.978	-0.251	0.246	0.312	-0.177	0.138	0.207	-0.603	0.242	0.0178*
Inflation	-0.037	0.327	0.911	0.124	0.261	0.636	-0.129	0.154	0.409	0.070	0.293	0.813
Industry, value added (% of GDP)	0.241	0.473	0.613	0.478	0.366	0.198	0.249	0.425	0.562	0.477	0.340	0.170
Variable	*Model R 3*			*Model R 3.1*			*Model R 3.3*			*Model R 3.5*		
	Coeff.	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*	*Coeff.*	*Standard errors*	*P value*
Researchers per million inhabitants	-0.001	0.0007	0.119	-0.0013	0.0007	0.081	-0.0014	0.0008	0.085	-0.002	0.0006	0.009 **
Expenditure per student	-0.012	0.0074	0.109	-0.0136	0.0078	0.084	-0.0140	0.0085	0.107	-0.015	0.0066	0.029 *
Internet users	0.008	0.0019	0.000098 ***	0.0081	0.0020	0.0001 ***	0.0074	0.0021	0.001 **	0.007	0.0016	0.00003 ***
Export of goods and services	-0.006	0.0056	0.314	-0.0048	0.0050	0.34	-0.0038	0.0059	0.518	-0.003	0.0053	0.536
Inflation	0.010	0.0079	0.215	0.0089	0.0077	0.248	0.0110	0.0087	0.211	0.009	0.0072	0.218
Industry, value added (% of GDP)	0.020	0.0092	0.034*	0.0212	0.0077	0.0076 **	0.0188	0.0092	0.047 *	0.012	0.0053	0.028 *
Interaction	4.19E-05	2.09E-05	0.0495 *	4.73E-05	2.18E-05	0.034 *	4.72E-05	2.38E-05	0.052 .	4.77E-05	1.82E-05	0.012 *

Notes: signif. Codes: 0 '***'; 0.001 '**'; 0.01 '*'; 0.05 '.'; 0.1 ' '; 1.

Source: prepared by the author.

Finally, the R 3 models reinforce the central argument of the study: SHC (researchers per million), public investment in tertiary education per student and digitalization (internet users) consistently explain economic growth in Latin America. Notably, the interaction between researchers per million and expenditure per student has a positive and significant effect in all robust models estimated. This empirical finding validates the assumption of political isomorphism proposed in the theoretical framework in that investing separately in higher education or SHC training is insufficient. It is essential to link both systems institutionally through collaborative governance arrangements that enhance their synergies. The positive interaction suggests that, in contexts where this connection is strong, the combined effect multiplies its benefits and favors sustained economic growth trajectories, in line with the findings of Grundke *et al.* (2018) and Locatelli (2018).

In general terms, the robust results confirm that SHC training is primarily driven by R&D spending, although this effect is temporary and contingent on the existence of stable institutional arrangements. Furthermore, it provides evidence to support the argument that digitalization positively and significantly effects economic growth; however, its contribution is more consistent when accompanied by adequate SHC density and robust educational policies. Consequently, economic growth is positively affected by both dimensions (SHC and digitalization); however, it is the interaction between investment in education and SHC that shows the most significant and sustained effect in the robust models.

These findings reinforce the diagnosis of Stezano (2021) and ECLAC (2016), highlighting the fact that Latin America faces structural challenges in effectively coordinating education systems, innovation systems and productive development policies. The study provides evidence that supports the need for PSC policies based on a comprehensive and long-term approach, where institutional strengthening is configured as a cross-cutting axis for accumulating technological capabilities, training of SHC and fully utilizing digitalization.

In short, robust quantitative results support the need to implement comprehensive PSC policies that focus not only on increasing investment in education and STI, but also on strengthening institutional capacities for coordinating between systems, as proposed by the PSC. The evidence suggests that SHC training, digitalization and economic growth operate as interdependent dimensions requiring a structural and long-term approach to consolidate themselves sustainably in the region.

6. CONCLUSIONS

The results obtained reinforce the relevance of the PSC model as an interpretive framework for understanding the dynamics between SHC training, digitalization and economic growth in Latin America. Empirical evidence shows that while investment in R&D and tertiary education drives the training of SHC and that SHC and digitalization both contribute positively to economic growth, these effects do not occur automatically or linearly but rather, are mediated by specific institutional structures.

In particular, the concept of political isomorphism emerges as a key concept for designing public policy. The findings indicate that, without collaborative governance mechanisms between higher education systems and national innovation systems, the relationship between SHC and educational investments may be limited or inefficient. The positive interaction observed between researcher density and public spending on tertiary education in its effect on economic growth precisely reflects the importance of such structural coordination, theoretically validating the notion of political isomorphism as a guide for policy design. These results suggest that institutional strengthening enhances not only the individual effects of educational investment or researcher training but also amplifies their combined impact on regional economic development.

From this perspective, it can be concluded that the main challenge for Latin America is not solely increasing spending on education or STI, but rather in consolidating lasting and coherent state policies that integrate both areas structurally. Therefore, it is a question of moving beyond fragmented and short-term approaches and advancing toward PSC strategies that simultaneously consider: *1)* the accumulation of technological capabilities; *2)* SHC training; *3)* the strengthening of institutional governance; and *4)* the functional integration of education and innovation systems.

Furthermore, this study identifies methodological challenges that open up future lines of research. These include the following:

1) The need to develop models that better capture the observed deferred and nonlinear effects, incorporating dynamic panel data techniques or structural equation models.

2) The importance of overcoming possible biases derived from unobserved heterogeneity which, although controlled by using fixed effects, could be explored in greater depth using mixed methods that integrate comparative qualitative and institutional analyses.

3) The inclusion of additional indicators that consider the quality of human capital, beyond its quantity, and the degree of sophistication of the innovation system in each country.

In summary, the findings of this study suggest that the region requires comprehensive and stable public policies capable of building an institutional ecosystem in which education, innovation and digitalization do not operate as isolated spheres, but as interdependent components of a process focused on sustainable development. This vision requires strengthening collaborative governance and political isomorphism as central pillars of any scientific, technological and educational policy strategy in Latin America.

ANNEXES

Link to consult the database and the R script:

https://drive.google.com/drive/folders/1yZMfWmC7sJE6mzo2epTtK4Q 83eHay999?usp=sharing

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[1] Although the concept of SHC is broader (and will be developed further later), in this paper it will be understood as: "researchers engaged in research and development are professionals who are dedicated to the design or creation of new knowledge, products, processes, methods or systems, and to the management of the corresponding projects. This includes PhD students (level 6 of ISCED 97) engaged in research and development" (World Bank, 2025). Meanwhile, the concept of Specialized Human Capital training refers to the teaching-learning process at the tertiary level, the result of which are the graduates.