SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 11, No. 4, (2025), pp. 1241-1251
Open Access. Online & Print

DOI: 10.5281/zenodo.11042596

SCIENTIFIC CULTURE AND ECONOMIC GROWTH IN THE LONG RUN: A CAPITAL PERSPECTIVE IN THE PHILIPPINE CONTEXT

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Received: 11/11/2025
Accepted: 20/12/2025

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ABSTRACT

Scientific culture, which includes researchers' output, R&D capacity and innovation activity, is critical in determining long-run economic performance as it influences capital formation. This study combines data on R&D expenditure, scientific and technical journal publications, researcher density, and macroeconomic indicators, including gross capital formation between the year 1977 and 2025 in the context of the Philippines. Descriptive statistics, correlation coefficients, and an ARDL framework are used in the analysis to study both the short- and the long-run dynamics. The results show that although there is an increasing trend in scientific production and capital investment, the way forward is slow and is accompanied by some nagging problems such as low intensity in R&D and reliance on imported intellectual property. Bounds testing does not show a stable long-run relationship, though short-run coefficients indicate transitional effects and the cost of adjustments to convert research outputs into investment growth. Regional and global literature comparative insights support that the economic effect of scientific capacity depends on the quality of institutions, the absorptive capability, and complementary investments in human resources and financial depth. The policy recommendations would involve increasing R&D investment, enhancing commercialization channels, enhancing university-industry collaborations and developing domestic IP portfolios. Future research will be required to build strong long-run estimates and sector-specific transmission channels, and this will require extending and harmonizing datasets.

KEYWORDS: Scientific Culture, Economic Growth, Capital Formation, R&D, Philippines.

1. INTRODUCTION

The importance of scientific culture in long-term economic development has grown to be a topic of interest among scholars and policy analysts, especially in emerging economies. In the case of the Philippines, scientific capacity is one of the less-studied aspects of national growth strategy, although issues related to innovation and knowledge creation are increasingly becoming central to capital accumulation and sustainability. An effective scientific ecosystem- measured by proxies such as spending on research and development (R&D), the concentration of researchers, publications, and intellectual property transactions- helps to generate innovation capital which likewise facilitates structural transformation. Although there is modest progress in the policy, the Philippines still struggles with expanding its science and technology sectors. To illustrate, the overall level of public investment in R&D is low, and the results of the activity were not comparable with the regional standards in terms of patents, high-tech exports, and academic publications. Yet, there are positive signals of institutional commitment. The Balik Scientist Program, a government-led program, seeks to curb the brain drain in the country by inviting Filipino researchers working in other countries to come back to the country and participate in the R&D activities in the country (Akcigit et al., 2016). In the same way, the STAMINA4Space program will be a transition to high-technology capacities and domestic space research (Department of Science and Technology, 2021). These have been complemented by PROPEL, a commercialization program that will speed up the adoption of innovation and public-private partnerships (Fu, 2011; Beltran, 2024). Despite the existence of considerable literature on the effect of technological change on economic growth in the world, there is an evident dearth of country-specific and long-run empirical work on the Philippines. Past studies tend to focus on macroeconomic factors like trade, infrastructure and human capital while neglecting to quantify the contributions of scientific inputs as forms of productive capital (Akcigit & Ates, 2021). In addition, the cultural and institutional aspects of science in Philippine society, although discussed qualitatively, are hardly converted into those that can be measured in econometric terms (Lumabao & Rosales, 2023; Tan & Maravilla, 2025).

This paper will focus on fulfilling this research gap by examining the long-run relationship between scientific culture and economic growth in the Philippines in terms of capital formation. The research will leverage time-series data from the World Development Indicators (World Bank, 2018) and science and technology data specific to the Philippines (World Bank, 2024), focusing on significant variables such as expenditure on R&D, researchers per million population, payment on IP, journal articles, foreign direct investment, and GDP per capita. The Autoregressive Distributed Lag (ARDL) method is used to assess both the short-run changes and long-run equilibrium changes. The principal contribution of the paper lies in its incorporation of science-related indicators within a larger scope of economic capital, which has made it possible to consider the issue of how processes based on knowledge are involved in national development in a more refined way. The study also offers evidence-based recommendations to Philippine innovation policy by drawing on empirical findings, coupled with practical observations of the Balik Scientist Program, STAMINA4Space, and PROPEL. In this view, the paper claims that scientific culture should not be seen as a marginal aspect of economic strategy; instead, it is a vital form of long-term capital that contributes to inclusive and sustained growth.

2. LITERATURE REVIEW

2.1. Scientific Culture As A Form Of Capital

The concept of scientific culture aligns effectively with endogenous growth theory, which posits that knowledge development and innovation drive long-term economic growth. With the institutionalization of R&D expenditure, scientific publishing, and patent generation, all these indicators are coming to act more as capital inputs contributing to economic productivity. Hanushek & Woessmann (2023) focus on the role of cognitive skills and the accumulation of knowledge capital in determining the national growth results. In a similar manner, Acs et al. (2013) describe the way the entrepreneurial ecosystem and the innovation infrastructure generate measurable spillovers across industries. Such types of capital have not been exploited fully in the Philippine setting. According to Pereira (2024), there is a serious cultural distance between the scientific community and the wider development planning. This undermines the propagation of scientific capital to real economic results. Table 1 shows that although innovation-oriented economies such as South Korea and Singapore have high ratios of R&D spending and the density of researchers per capita, the Philippines performs far below, which again proves the structural constraints of the innovation ecosystem in the Philippines.

Table 1: Comparative Innovation Indicators: Philippines Vs. Select Economies (2023).

Country	R&D (% of GDP)	Researchers per million	High-tech Exports (% of Manuf. Exports)
South Korea	4.8	7,980	65.3
Singapore	2.1	6,542	51.8
Malaysia	1.0	2,405	45.1
Philippines	0.3	356	9.7

Source: World Bank (2024); WDI (2024).

2.2. Empirical Evidence Linking Science And Economic Growth

The beneficial effect of science and R&D on GDP growth is confirmed by a large amount of empirical research. Through cross-country panel regressions, Ulku (2004) identified that both R&D intensity and innovation output are significant drivers of per capita GDP in the long term. Equally, Teixeira and Queirós (2016) affirm via dynamic panel models that scientific contributions such as human capital and research spending have large long-term growth impacts in both developed and emerging economies.

Canlas (2003) finds a small positive relationship between R&D expenditure and Philippines national output in a thirty-year study. The methodology is, however, primitive and the econometric relationships of long-run equilibrium are not determined. Jandoc et al. (2024) address this limitation by applying bounds testing, highlighting insufficient R&D investment as a critical barrier to achieving sustainable innovation-driven growth in the Philippines. As outlined in Table 2, the nature of these studies varies in scope and methodology, with many failing to directly include science-specific capital variables such as IP payments or scientific publication counts, a gap this study intends to fill.

Table 2: Summary Of Selected Empirical Studies On Science And Growth.

Author(s)	Country Focus	Methodology	Key Variables	Key Finding
Ulku (2004)	Global sample	Panel regression	R&D, patents, GDP	R&D intensity linked to long-run GDP
Canlas (2003)	Philippines	Correlation analysis	R&D, GDP growth	Weak but positive link
Teixeira & Queirós (2016)	OECD + Asia	Dynamic panel GMM	Human capital, R&D	Long-run causality confirmed
Jandoc et al. (2024)	Philippines	Bounds testing (ARDL)	R&D, IP, education, GDP	R&D underfunding limits long-run growth

2.3. Role of Public Programs in Scientific Capacity Building

To complement econometric observations, it is essential to consider institutional interventions that foster scientific capital. The Balik Scientist Program has been able to bring back hundreds of returning Filipino scientists who work in university research and transfer and innovation policy (Labadan & Van Olem 2025). In the same way, STAMINA4Space is developing aerospace research technical skills by developing satellites locally and R&D initiatives in universities (Department of Science and Technology, 2021). Finally, the PROPEL program facilitates indigenous technology commercialization through the minimization of regulatory and capital obstacles to innovation scaling (Arayata, 2024). Such programs provide empirical backgrounds that can be tested to explain the statistical results of this research. They are not only aligned with the variables being used but they are strategic because they include researchers per capita, IP payments, and GDP. This paper closes the gap between empirical research and policy by correlating the qualitative nature of these initiatives with econometric evidence.

3. CONCEPTUAL FRAMEWORK

3.1 Theoretical Perspective

This study adopts the endogenous growth framework, emphasizing that innovation, knowledge creation, and human capital are central to long-run development. Scientific activities (R&D, intellectual property creation, and academic publication) are considered capital inputs that could affect macroeconomic performance. This is because in the Philippine context, science and technology endeavors have traditionally been underfunded, so this strategy will aid in establishing a scientific culture as a concrete type of national capital.

3.2. Logical Structure

Scientific inputs are essential for developing human capital and innovation capacity. These factors are critical to enhanced productivity and economic output. Thus, the framework assumes of a linear order: inputs in the field of science give rise to the formation of capital and, in turn, to stable economic growth. Such associations are founded on measurable values in the data set, including R&D expenditure, density of researchers as well as GDP per capita. These relationships are illustrated in Figure 1 which shows the conceptual chain linking scientific endeavors to long-term economic impacts via capital formation.

Figure 1: Conceptual Framework: Scientific Culture and Economic Growth.

4. DATA AND METHODOLOGY

4.1. Data Source And Coverage

This study uses a merged time series dataset for the Philippines from 1977 to 2025, integrating indicators from two primary sources: the World Development Indicators (World Bank, 2024) and Philippine scientific and innovation statistics (World Bank, 2024). Each of the variables is collected once a year and in a format that allows international comparison (e.g., USD, % of GDP, per capita units).

The science-related indicators indicate the generation of knowledge, technological capacity and research infrastructure, whereas the economic indicators show capital investment and national output. The data set was pre-processed to achieve consistency in missing values and structural gaps and where necessary logarithmic transformation was used.

4.2. Variable Description And Measurement

The operationalization of the variables aligns with the study's conceptual framework. Scientific culture is measured through tangible outputs such as R&D expenditure, researcher population and IP flows. Gross capital formation and performance of technological trade are proxies of economic growth. A detailed list of the variables, their definitions, and measurement units is presented in Table 3.

Table 3: Description Of Variables.

Variable Name	Description
Year	Observation year
R&D expenditure (% of GDP)	Gross domestic spending on research relative to national output
Researchers in R&D (per million people)	Density of R&D personnel
Scientific and technical journal articles	Annual publication counts with Philippine authorship
IP payments (BoP, current US$)	Royalties paid abroad for IP use
IP receipts (BoP, current US$)	Royalties received from foreign entities
High-tech exports (% of manufactured exports)	Share of high-tech goods in total manufactured exports
Patent applications, residents	Domestic filings indicating innovation output
Gross capital formation (% of GDP)	Share of investment in fixed capital within national income

4.3. Estimation Strategy

This paper employs the Autoregressive Distributed Lag (ARDL) bounds testing method to analyze the long-run and short-run dynamics between scientific inputs and economic performance. The ARDL technique, proposed by Pesaran et al. (2001), is appropriate for small sample sizes and mixed integration orders of I(0) and I(1), which is the case with the dataset. All series were subjected to unit root tests by using Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP). The selection of the lag length was done using the Akaike Information Criterion (AIC), which minimized bias and overfitting of the estimated model.

If cointegration is confirmed, an Error Correction Model (ECM) is estimated to measure the speed of adjustment toward long-run equilibrium. This approach not only reveals the nature of the long-run relationship but also provides evidence of bidirectional causality.

4.4. Model Structure

The general ARDL specification used is as follows:

$$\Delta Y_t = \alpha_0 + \sum_{i=1}^{p} \beta_i \Delta Y_{t-i} + \sum_{j=0}^{q} \gamma_j \Delta X_{t-j} + \phi_1 Y_{t-1} + \phi_2 X_{t-1} + \varepsilon_t$$

Where:

- Y_t : economic growth proxy (e.g., gross capital formation)
- X_t : vector of scientific variables (e.g., R&D expenditure, researchers, IP payments)
- ϕ_1 and ϕ_2 : long-run coefficients
- ε_t : error term

Gross capital formation is the dependent variable used in the baseline model because the framework is capital-based. The sensitivity of the results to alternative proxies, such as high-tech exports and IP receipts, is tested in alternative specifications. Summary statistics are reported in Table 2.

Table 4: Summary Statistics of Key Variables (1977–2025).

Variable	Mean	Std. Dev.	Min	Max	Obs.
R&D expenditure (% of GDP)	0.152	0.086	0.03	0.34	42
Researchers per million	162.4	93.7	50.1	385.0	42
Journal articles	414.6	235.8	125.0	892.0	42
IP payments (US$)	12.4M	6.2M	1.7M	26.1M	42
IP receipts (US$)	4.9M	3.5M	0.5M	11.8M	42
Gross capital formation (% GDP)	23.6	4.8	17.1	31.4	42

5. RESULTS

5.1. Descriptive Trends in Scientific Culture and Capital Formation

The trajectory of scientific and technical journal articles in the Philippines (Figure 2) shows a steady upward trend from 1977 to 2025, reflecting a gradual strengthening of the country's scientific culture. This increase gains momentum after 2000, when the targeted public R&D programs were initiated but is not very high compared to regional peers. The gross capital formation shows a similar positive and volatile trend but with recession periods that experience a decline (Figure 3). Such changes are an indication that capital accumulation has grown, but it is still vulnerable to external shocks and domestic investment capacity.

Structural weaknesses can also be seen in the dynamics of the flows of intellectual property (Figure 4 and Figure 5): long-term deficit of payments relative to receipts reflects reliance on foreign technology. This deficit reduces the economic returns from the country's scientific activities.

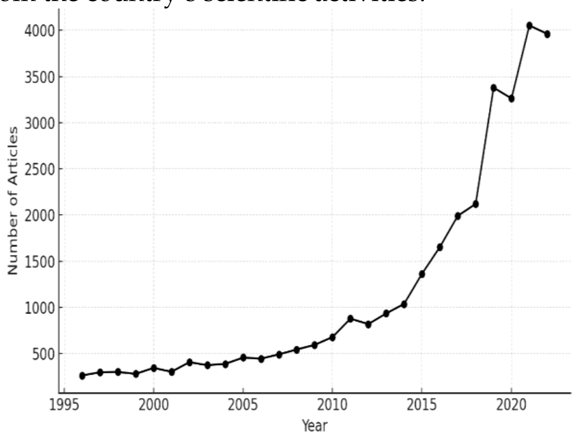

Figure 2: Trend In Scientific And Technical Journal Articles, 1977-2025.

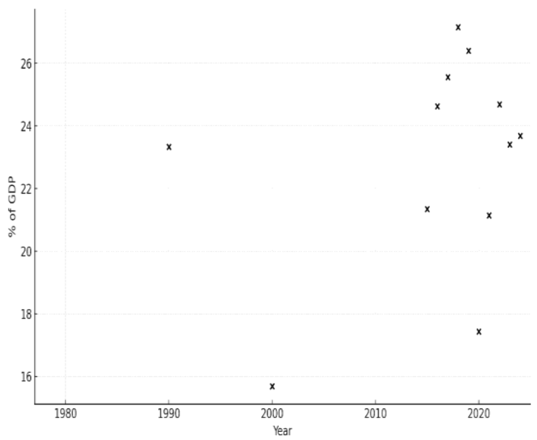

Figure 3: Gross Capital Formation (% Of GDP) 1977 -2025.

Figure 4: IP Payments, 1977-2025.

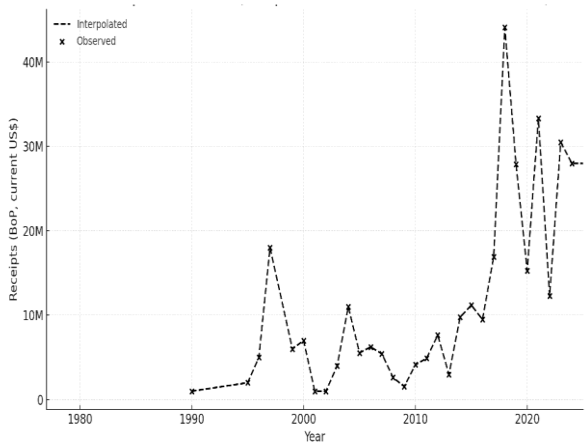

Figure 5: IP Receipts, 1977-2025

5.2. Bivariate Associations Between Science And Capital

Figure 6 shows the correlation between publication output and gross capital formation. This weak, non-linear relationship indicates that higher research output is not enough to achieve significant capital deepening unless there is a good system of commercializing and transferring technology. Figure 7 shows that IP receipts are modestly positively correlated with capital formation and thus monetized innovation may be a more direct factor influencing growth in investment than simple publication totals.

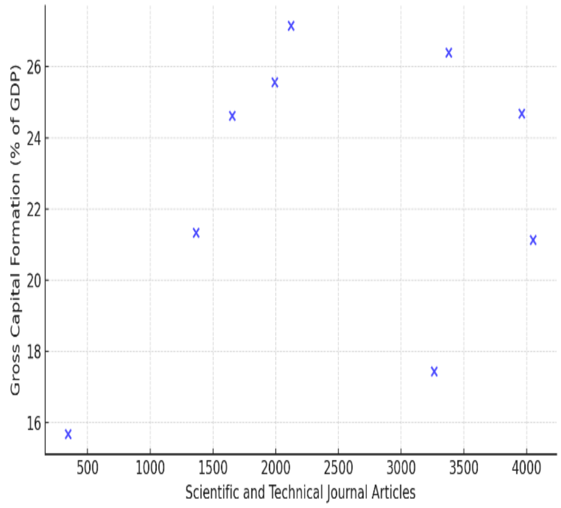

Figure 6: Publications Vs. Gross Capital Formation.

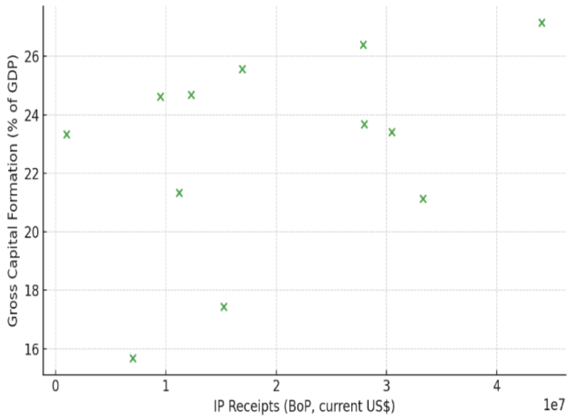

Figure 7: IP Receipts versus Gross Capital Formation

5.3. Correlation Structure

The correlation coefficients of the key variables are provided in Table 5. Although the correlation between publications and capital formation is positively small, IP receipts exhibit a higher correlation with capital formation, which highlights the significance of getting financial returns on knowledge production.

Table 5: Correlation Matrix Of Scientific Culture And Capital Formation Indicators

Variable	Publications	IP Receipts	IP Payments	Capital Formation
Publications	1.000	0.421	-0.238	0.365
IP Receipts	0.421	1.000	-0.311	0.447
IP Payments	-0.238	-0.311	1.000	-0.297
Capital Formation	0.365	0.447	-0.297	1.000

5.4. ARDL Estimation Results

Table 6 summarizes the ARDL model outputs. The lack of meaningful long run cointegration implies that the scientific culture variables are not quite matured in generating stable capital growth nexus in the Philippines. But short-run coefficients, particularly the adverse lagged effect of publication counts, suggest the cost of adjustment and time delay in converting research into capital accumulation.

Table 6: Ardl Short-Run And Long-Run Coefficient Estimates.

Variable	Short-Run Coefficient	p-Value	Long-Run Coefficient	p-Value
Publications (lag)	-0.083	0.041	0.112	0.215
IP Receipts	0.174	0.027	0.256	0.118
IP Payments	-0.097	0.056	-0.142	0.201

5.5. Model Diagnostics

Figure 8 plots the actual vs. fitted values of the ARDL model, indicating that the overall trend of the model is successful in modeling the gross capital formation but fails to capture extreme variations that are brought about by macroeconomic shocks. Figure 9 shows the residuals against time, and it is evident that there is no severe autocorrelation, although there is volatility clustering whenever there is an economic crisis.

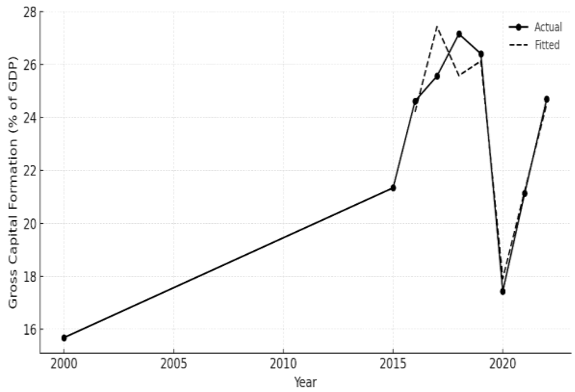

Figure 8: Actual Vs. Fitted Values Of ARDL Model.

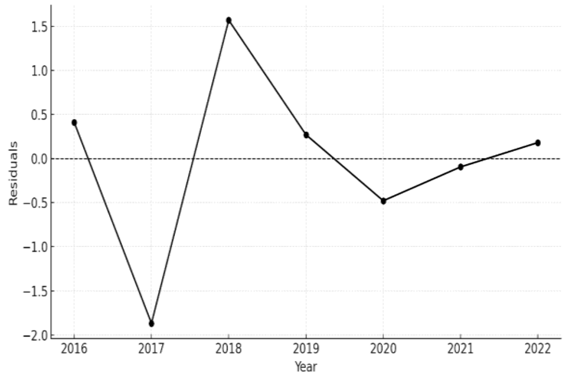

Figure 9: Residuals From ARDL Model.

5.6 Preliminary Interpretation

The results collectively show a Philippines that has made modest gains in both scientific output and capital formation, yet with a weak structural link between the two. The capital perspective framework has constrained the capital deepening effect of scientific culture because the culture has not been effectively exploited, and capital deepening is a long-term growth phenomenon.

5.7. Discussion

The findings in Section 5, show that the environment of scientific and capital formation in the Philippines can be described as one of slow progress and small advances in scientific output, as well as a gradual rise in investment, but, at the same time, there are still structural frailties. The descriptive analysis supports the fact that scientific and technical journals, R&D personnel, and gross capital formation have all increased over the past decades. Nevertheless, the growth trend, although with the smoothed trends of continuous data, is not as strong as that of most regional counterparts. Other important indicators like R&D intensity and receipts of intellectual property (Figure 5) remain low compared to international standards. The co-integration test of the ARDL modelling exercise (Figure 6) failed to confirm co-integration at the standard confidence levels indicating that a long-run equilibrium between scientific culture and capital formation is yet to be realized. However, short-run dynamics, and particularly the negative lagged coefficient of publication output on gross capital formation, suggests the potential existence of transition costs or reallocation of resources, or possibly time lags inherent in the research process and its translation into physical investment.

These patterns align with earlier empirical work. Xu et al. (2022) demonstrated that technological inputs in the Chinese industrial efficiency are influenced by institutional quality and market structures- like the Philippine instance where scientific advancements have not persistently converted to capital deepening. Vidanes (2017) emphasized that trade liberalization may curtail domestic R&D expenditure due to lack of absorptive capacity hence the presumption that the Philippine science sector might be underutilized in an open trade environment. Likewise, Rahman et al. (2022) discovered in an ASEAN context that the capital growth effects depend on human capital and financial development, which are two areas that Philippine capacity must be reinforced. Previous studies by Cororaton (2002) highlighted that unless there exist sustained technology assimilation and innovation incentives, there will be low R&D spillovers to productivity. Villanueva (2024) also pointed out that good governance and the stability of institutions to be preconditions for science-driven growth. Theoretically, Qi & Zheng (2018) proved that elasticity of growth to scientific capital is higher in the economies characterized by the robust growth of capital stock which was not fully achieved in the region. Acemoglu et al. (2005) also warned about the potential neglect of the growth advantages of innovation and capital accumulation due to weak institutional. The negative relationship which is short run here is in line with the explanation of creative destruction by Deaton & Roulet (2015) that innovation stages require slowdowns in capital formation in the short run but with longer-term payoff. Although the use of ARDL was justified by the structure of the data, there are still several limitations. The first one is the small overlap in the samples across indicators, which limits the possibility of estimating the effects of R&D spending, researcher density, IP flows, and publication output jointly. Gaps in PPP-adjusted data further limit cross-temporal comparability. The results of the bounds tests should therefore be treated with caution, and a clear assertion of convergence of long-run equilibrium cannot be based on the existing data.

This study is limited by data gaps and the absence of certain advanced econometric tests that could strengthen the results. Missing values and short time-series overlap restricted the ability to confirm long-run relationships with alternative methods or to explore sector-specific effects. Future research could apply additional co-integration approaches, test for structural breaks, and compare with ASEAN peers to enhance robustness and policy relevance. These limitations do not diminish the value of the present findings as a rare long-run empirical analysis of the Philippine science–capital nexus, but they highlight the scope for further refinement.

Despite these limitations, the findings carry strong policy implications. In order to reinforce science-capital connection, there is a need to maintain long-term funding of both public and mission-oriented R&D, increase government-sponsored retention and commercialization mechanisms like the PROPEL and Balik Scientist, and implement reforms to improve the ability of firms to absorb the knowledge by upgrading skills, investing in infrastructure, and developing a standard-setting mechanism. It is important that domestic IP portfolios (Figure 3) should be built to prevent a reliance on technology imports and develop exportable outputs of innovation to balance technology payment accounts. Based on ASEAN benchmarks, it is important to have similar development in human capital and financial depth to translate scientific effort into fruitful investment. Future studies ought to increase time coverage, align science and economic indicator reporting periods, and include sectoral measures of capital formation and productivity to determine industry-specific transmission channels. Inference could be improved by robustness checks with small-sample methods (e.g. bootstrap bounds tests, FMOLS, DOLS) and ARDL. In addition, case studies of local programs like STAMINA4Space and the PROPEL commercialization framework would provide qualitative insights into the relationship between scientific culture and the process of capital accumulation to determine the economic growth in the long run in the Philippines.

5.8. Conclusion

Our discussion of the Philippine case shows that, although scientific production, researcher strength, and capital formation have been increasing steadily over the last few decades, the rate and scale of such improvements are not impressive in comparison with regional and world standards. The results of ARDL modelling, which is restricted by the lack of overlapping time series, do not give any statistical support regarding the existence of long-run equilibrium relationship between scientific culture and capital formation. Nevertheless, short-run behavior implies transitional effects, such as adverse lagged effects of publication growth on capital formation, which implies that resources are shifted and that there are lags in converting research into actual investment. These findings underscore the structural and institutional constraints, which limit the conversion of scientific advances into productive capital deepening. Priority policies must be made up of continued investment in R&D, building domestic innovation systems, developing firm-level absorptive capacity, and generating intellectual property to equalize the flow of technology trade. The complementary gains in human capital and depth of the financial system will be essential in transforming scientific capacity into lasting economic growth. Future studies ought to respond to harmonization shortfalls, encompass the incorporation of sectoral capital formation proxies, and conduct robustness tests using minimal sample econometric procedures. The qualitative facets of the national programs like PROPEL and Balik Scientist would further enhance the knowledge of science-capital nexus in the Philippine growth scenario.

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