Business, Management and Economics Engineering
ISSN: 2669-2481 / eISSN: 2669-249X
2026 Volume 24 Issue 01

HUMAN CAPITAL, INNOVATION, AND ECONOMIC GROWTH IN PERU: AN EXTENDED MRW-ARDL ANALYSIS (1990–2020).

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Abstract
This paper examines the determinants of economic growth in Peru over the post-liberalisation period 1990–2020 within an extended Mankiw–Romer–Weil (MRW) neoclassical framework augmented with foreign direct investment (FDI), trade openness, innovation proxied by resident patent applications, and disaggregated public expenditure on education and health per capita. The optimal model, ARDL (1,1,0,1,1,1,1,0), is selected from 64 candidate specifications via the Akaike Information Criterion, achieving an R^2 of 0.952 and an F-statistic of 12.56. Results reveal a negative first-lag auto-effect on GDP per capita ($\beta = -0.443$), indicative of structural growth inertia. Trade openness emerges as the single most robust and statistically significant growth driver ($\beta = 0.318$, $p < 0.05$), while public expenditure on education per capita contributes positively and significantly ($\beta = 0.263$, $p < 0.05$). FDI exerts a positive but marginally significant contemporaneous effect ($\beta = 0.209$, $p = 0.062$). Innovation proxied by resident patent applications exhibits a consistently negative and insignificant association with output growth ($\beta = -0.032$), revealing a structural disconnect between formal innovation activity and productive transformation. Bounds cointegration is confirmed (F-statistic = 5.623), and CUSUM/CUSUM-squared tests confirm full parametric stability across the estimation window. These findings carry direct comparative implications for resource-dependent developing economies in Asia, demonstrating that trade-led openness and targeted human capital investment—rather than innovation proxies alone—represent the most reliable near-term drivers of per capita income growth at an intermediate stage of development.

Keywords: *Human Capital; Economic Growth; ARDL; MRW Model; Foreign Direct Investmen; Developing Economies*
JEL Classification: O11, O15, O31, F21, C22

Introduction
In the modern knowledge-based global economy, the relationship between human capital, innovation and economic growth has taken a revived interest in empirical research in growth (Zeynalov, 2025). There is a growing emphasis on the idea that economic performance in developing and middle-income countries is not solely reliant on the traditional process of accumulating capital but the ability of the economies to build capacity of producing qualified human resources, developing innovation systems and that they can integrate into global markets (Kaplinsky & Kraemer-Mbula, 2022; Mengesha & Singh, 2023). According to Cross-country and panel studies, empirical evidence shows that human capital development in the form of education, health and skill formation continues being a core factor in enhancing productivity and overall economic growth in the long run (Bykova et al., 2024).

Simultaneously, the ability to innovate and embrace technology is becoming the differentiator of the capacity of economies to turn investments in human capital into a long-lasting growth and structural change (Sairmaly, 2023).

Starting with the seminal neoclassical framework of Solow (1956), which placed residual productivity growth on top of exogenous technological progress and that then the later generation of endogenous growth theorists, who have steadily sharpened their interpretation of how knowledge, skills, health, Institutional bottlenecks, limits of absorptive capacity, and structural rigidities which weaken, or reverse, the apparent theoretical relations, are often sources of institutional bottlenecks in relation to developing and emerging economies (Braunerhjelm & Henrekson, 2024).

The case study of Peru presents a solid and empirically manageable study on this tradition. During 1990-2020, Peru experienced one of the most structural changes in Latin America, replacing an economy in a very weak state, with continuing GDP contractions averaging up to 30 percent, dysfunctional fiscal policies, and almost complete lack of access to the international capital markets, the country evolved into one of the most open, macroeconomically stable, and FDI-friendly economies in the region. In 2010 US dollars, GDP per capita increased between 1990 (US $ 2,638) and 2019 (US $ 6,183) where it rapidly dropped to 11.1 percent in 2020, following the COVID-19 pandemic (Olivera, 2023). The average growth rate of 2001-2010 was greater than 5 percent, which ranks Peru among the economies that have been developing at accelerated rates in Latin America (Rendon, 2025). However, this performance has been structurally lopsided: commodity-price-conditional, institutionally frail and loosely related to diffuse-based human capital accumulation and innovation potential.

These structural characteristics are not peculiar to Peru. They describe a general group of resource endowed, upper-middle-income, developing economies in Asia and the Pacific that includes Peru, namely Indonesia, Vietnam, Mongolia, Kazakhstan, and Papua New Guinea which are characterised by their reliance on commodity exports, a partial human capital formation process, a nascent system of innovation and growth processes primarily shaped by external demand and FDI inflows as opposed to domestic productivity transformation (Cateia & Savard, 2026; Dempere et al., 2023). JAE has maintained its continuous publishing of research on this very crossroad of international economic opening, human capital investment and growth dynamics within developing Asia.

The current research also fits into this line of tradition by offering a rigorous ARDL-based empirical analysis of Peru as a structurally comparable archetype, whereby the findings have direct applicability to the Asian development experience (Cateia & Savard, 2026; Hamed et al., 2024). The Econometric literature on the development of Peru, even with the abundance of growth details, is relatively bland in the international journals. The majority of available studies follow a platform Latin American panel, which hides nation-specific dynamics, or shorter time ranges and less vital specifications that fail to capture non-stationarity, cointegration, and short-run dynamics.

Based on the structural revolution of Peruvian economy and theoretical perspectives of augmented MRW framework, this paper analyses macroeconomic determinants of long-run growth in a resource-dependent developing economy. The analysis is based on the following research question: To what extent does human capital investment, innovation activity, foreign direct investment as well as trade openness contribute to the economic growth in Peru in the post-liberalisation period (1990-2020)? Moreoever, how much has foreign direct investment per capita facilitated economic expansion and is this facilitation a lasting spillover process or a transient capital formation impact limited by the enclave nature of resource-sector FDI? Does human capital in the form of public expenditure on education per capita, public expenditure on health per capita and resident patent applications as an innovation proxy explain the growth pattern in Peru, and is there any sign that formal innovation activity and productive transformation are disconnected? Finally, what has trade openness done to the economic growth and what are the implications to the structurally similar resource-dependent developing economies in Asia? Combined, the paper explains the relative significance of such growth determinants and empirically test these hypotheses within an ARDL bounds-testing model to offer evidence that is not limited to Peru alone but also to structurally equivalent developing economies.

Literature Review

2.1 Theoretical Foundations: From Solow to the Extended MRW Model

The classical neoclassical growth theory of Solow (1956) and Swan (1956) explains long-run per capita income as a product of saving and growth in population, and also exogenous technological advancement, with no human capital as a separate factor of production. Mankiw et al. (1992) first incorporated the systematic aspect of human capital in the neoclassical model by adding human capital to the Solow model as a third variable of accumulation besides the physical capital and labour as raw material. Their empirical tests using a sample of 98 countries showed that the augmented model explained cross-country variation of income and produced output elasticities of about one-third, in terms of physical and human capital, which were widely similar to factor income shares. Furthermore, the MRW developmental framework has been the main departure point of empirical literature on growth. The latest update full review on the issue of whether the Solow model or the MRW specifications were more effective in explaining the existence of income differences among the advanced economies is conducted by Thach (2025) who demonstrates that the MRW augmented specification outperforms the basic Solow model using Bayesian Monte Carlo simulations.

Endogenous growth theory: Romer (1990) and Lucas (1988) gave intellectual groundwork to this concept and have found that knowledge accumulation through R&D and human capital spillovers is endogenous in the long-run growth. The spatial MRW model of Fischer (2010) and later agglomeration effects of human capital spillovers in core areas confirms the existence of spatial heterogeneity in the form of geographically concentrated returns to education investment, as well as the structural constraints of benefit accrual to peripheral economies exposed to the effect- such as in Peru where the human capital stock and innovative ability is concentrated on the spatial scale.

Combined, the theoretical literature produces conflicting predictions that cannot easily be reconciled. According to the canonical MRW model, the accumulation of human capital both in the form of education and health must lead to both broad and symmetric increases in per capita income, assuming that savings rates and population growth remain constant. Endogenous growth theory however, is one which suggests that the returns to human capital are not linear and can be self-reinforcing as a result of knowledge spillovers and R and D investment which could be non-existent or structurally constrained in commodity-dependent economies. Spatial extensions of the MRW model also imply that the returns are spatially clumped, and so the aggregate country level estimates which are generated by standard time-series models can conceal very important regional heterogeneity. The current research fits within this tension in that it evaluates the MRW framework on the national level of Peru, and recognises the limitations posed by structural factors to the applicability of both endogenous growth and spatial spillovers mechanism in a resource-export-dependent situation.

2.2 ARDL-Based Growth Empirics in Developing Economies

Bouattour and Helali (2026) state that the ARDL bounds-testing framework has received widespread use in single-country time-series studies of the relationship between the long-run growth rate and short-run regressors, due to its capacity to tolerate mixed I(0)/I(1) regressors, simultaneous estimation of both short-run and long-run parameters and lack of pre-testing bias due to integration order assumptions. Wegari et al. (2023) used the ARDL bounds test on the human capital-growth nexus in Ethiopia between 1980 and 2020 and concluded that there was a significant nexus of cointegrating the long-run transmission of the human capital-growth nexus, where the primary transmission method was through the improvements of the labour force quality. Alam (2023) has verified that Indian human capital and GDP are cointegrated, with long-run causality being human capital-to-growth long-run causality, which can be verified by using the ARDL bounds test. Using Brazilian regional data under the augmented MRW framework, Moreira et al. (2023) found that growth is positively contributed to by human capital. However, the substantial role of physical capital accumulation continues to happen as a proximate determinant of growth in Brazil. These three studies give prior methodological precedents as well as directly similar outcomes to the current Peru study.

2.3 FDI, Trade Openness, and Growth

The FDI-economic growth relationship is theoretically caused by capital formation, transfer of technology, managerial spillovers, and access to export markets, although it is empirically conditional on the extent of absorptive capacity. Borensztein et al. (1998) made the important observation that FDI can increase economic growth only after the stock of human capital of the host country reaches some minimum level. More recent panel studies have verified this conditionality: Labidi et al. (2024) report that the point of contact between FDI and growth occurs through governance, which is found to be relevant across African developing economies, whilst Martins (2023) report a great deal of heterogeneity in the growth effect of FDI between income groups. In the case of Latin America, Haque et al. (2022) discovered that the overall impact of FDI in 19 economies was statistically insignificant, and only high-income countries in the region had positive impacts. Yauri Illapuma and Arevalo Tuesta (2025) used fixed effects panel estimation to estimate eight South American economies, of which Peru fell under the years 2003-2018. They reported a positive relationship between human capital and growth, and also established heterogeneous FDI effects by the composition of sectors.

In the developing economies where, one has comparative advantages in the exportation of primary commodities, trade openness tends to have more stable positive growth results. Records of ECLAC 2023 indicate that the main structural correlation in convergence growth among members of the Pacific Alliance is through trade integration (Bressan & Borba Gonçalves, 2023). The data confirm trade openness as a desirable development factor to Asian observers, especially in the economies of Vietnam, Indonesia, and Central Asia, which have now deployed an outward-oriented development policy since the 1990s (Nguyen et al., 2026). It should be noted though that not all the above consensus on trade openness would be universal. A number of studies record non-linear relationship whereby openness growth dividend is conditional to a minimum point of institutional quality, domestic productive capacity, and export diversification. In a situation where trade is concentrated in primary commodities which have a low value-added content as in the case of Peru where copper, silver and gold constitute more than half of the value of exports, the growth multiplier of openness can be very low as compared to economies where manufacturing or services exports dominate the composition of trade. This is an empirically significant distinction in interpreting the results of the current study, but this difference differentiates the Peruvian experience of export-led growth with those of Vietnam or South Korea that are sometimes used as analogous examples.

2.4 Innovation and the Patent–Growth Disconnect

The recent enhancement of the innovation–growth nexus in developing economies has been an already well-documented paradox of structure that patent behaviour and expressed expenditure on formal R&D are loosely linked with aggregate productivity gains, especially in the enclaves' sector with low rates of diffusion into the overall productive core. The Garcia and Crawley (2024) Science, Technology and Innovation Outlook finds the weak knowledge-diffusion infrastructure, the limited industry-academia connections, and inadequate supply of STEM graduates as the main reasons for this disconnection in middle-income developing economies. The CS-ARDL framework is applied to resource-rich and resource-poor MENA economies, and the results of Dahmani and Mabrouki (2025) indicate that in the short run, the impact of capital stock and innovation on growth is significant. Still, their role is much more context-specific and negated by Dutch Disease dynamics in resource-abundant settings. Recording considerable asymmetric impacts of health capital on Chinese economic development, Jiang and Wang (2023) present an NARDL framework, which serves as an effective Asian comparator of the relationship by bypassing this paper.

On the other hand, a pattern is adopted which is a straightforward motivation to the current work. The available literature on FDI, trade and innovation in developing economies has shed light on a shared conclusion: the overall theoretical claim of a consistent growth dividend associated with openness and human capital investment, broken in the sample-wide, but fragmented in the country-specific case of structural restrictions unique to resource-dependent economies. The works of Haque et al. (2022), Dahmani and Mabrouki (2025) and Labidi et al. (2024) illustrate weak or insignificant FDI effects on the economy of Latin American middle-income countries; evidence of the inability of innovation indicators to translate into long-run productivity gains in resource-rich MENA countries; and that the FDI–growth channel is mediated by the quality of governance. Importantly, none of these papers uses the extended MRW framework using Peru as a one-country time-series, and none uses human capital further decomposed into education spending, health spending, and innovation as simultaneous in the same ARDL. The present paper directly covers that gap.

2.5 Research Gap

Although the literature above seems analytically enriching, there is a dearth of empirical evidence on determinants of growth in Peru in a rigorous time-series, theoretically based methodology in the global literature. The bulk of cross-country research considers Peru as one of the observations in a panel, hiding country-specific structural dynamics. The limited Peru-centric research has used knowledge of shorter time periods, fewer complexities, or has not captured relevant variables like disaggregated human capital spending or innovation proxy variables. This paper bridges that gap by offering the first ARDL implementation of the extended MRW model on Peru throughout the 1990-2020 sample, using knowledge of the post-2020 empirical growth literature and establishing comparative relationships with Asian developing economies with similar structures.

Theoretical Framework

3.1 The Augmented MRW Model

This work is theoretically based on the human capital-augmented Solow model of Mankiw et al. (1992). The specified production technology is a Cobb-Douglas function:

$$Y(t) = K(t)\alpha \;\; H(t)\beta \;\; [A(t)L(t)]1-\alpha-\beta, \quad \alpha + \beta < 1$$

with the aggregate output Y, physical capital K, human capital H, raw labour L expanding at an exogenous rate n and labour-augmenting technology A expanding at a rate g. The model can be solved in steady-state to reach a steady-state path conditioned on the rate of accumulation of physical capital (sk), human capital (sh), population (n) and the system of depreciation plus technological advancement (g + 8). The log-linearised steady state transition equation inequality of per-worker income is of the form:

$$ln(Y/L)^* = ln(A_0) + gt + \alpha/(1-\alpha-\beta)\ ln(sk) + \beta/(1-\alpha-\beta)\ ln(sh) - (\alpha+\beta)/(1-\alpha-\beta)\ ln(n+g+\delta)$$

The current paper builds upon the MRW model in four aspects: (i) public investment per capita (IPpc) as a state-driven machinery of capital formation; (ii) FDI per capita (FDIpc) as a measure of technology transfer, complementary capital formation, and externalities in its external sector; (iii) trade openness (AC) as a measure of the external-sector climate that essentially defined Peru in 1990; and (iv) resident patent applications (PAT) as a measure of domestic innovation capacity in line with the Romer (1990) The extended model for estimation, expressed in log-differences, is:

$$\Delta lnGDPpct = f(\Delta lnGDPpc(t-1),\ \Delta lnIPpct,\ \Delta lnFDIpct,\ \Delta lnPATt,\ \Delta lnACt,\ \Delta lnGPEpct,\ \Delta lnGPSpct)$$

3.2 ARDL Bounds-Testing Approach

Transforming to the ARDL bounds-testing procedure of Pesaran et al. (2001) has three main reasons. First, it takes into consideration regressors of both mixed integration order I(0) and I(1), which is essential in short annual time series where the results of unit root tests are often inconclusive. Moreover, it provides asymptotically sound F-tests and t-tests to test the null that there is no long-run relation without making a priori tests on the order of integration. Furthermore, the error correction representation is an all-encompassing characterisation of both short-run dynamics and long-run equilibrium adjustment in one consistent form.

The unrestricted error correction form of the ARDL(p, q_1, …, q_7) model is specified as:

$$\Delta lnGDPpct = \alpha_0 + \Sigma_i\varphi_i\ \Delta lnGDPpct-_i + \Sigma_k\Sigma_j\ \beta_{kj}\ \Delta x_k,t-_j + \theta_0 lnGDPpct-1 + \Sigma_k\theta_k x_k,t-1 + \varepsilon t$$

The null hypothesis of no long-run relationship (H_0: $\theta_0 = \theta_1 = \ldots = \theta_k = 0$) is tested using the F-bounds and t-bounds critical values from Pesaran et al. (2001) Case III (unrestricted intercept, no trend). The optimal lag structure is selected by minimising the Akaike Information Criterion (AIC) over 64 candidate models with a maximum of one lag per variable, and T = 31 as an upper sample size constraint. After the presence of cointegration, the Error Correction Model (ECM) describes the rate of adjustment to the long-run equilibrium.

3.3 Diagnostic and Stability Tests

The model adequacy is evaluated by five diagnostics, namely: Breusch Godfrey LM serial autocorrelation test (order 1 and 2); the heteroskedasticity test by White; Jarque Bera test of normality; a simple correlation matrix of exogenous variables to measure multicollinearity; and CUSUM / CUSUM-squared parametric tests of stability of models to evaluate structural changes.

Methodology

4.1 Data Sources and Variable Description

All data is annual and ranges from 1990 to 2020 (T = 31), the entire period of post-liberalisation since structural adjustment up to the COVID-19 shock. Variable definitions, data sources and transformations are summarised in Table 2. All monetary variables are expressed in constant 2010 US dollars using the deflator of the GDP of each country and then log-transformed (prefix DLN denotes first log-differences) to both permit interpretation of elasticity and to hold the variables constant so that they are stationary.

Table 2. Variable Operationalisation, Definitions, and Data Sources

Variable	Symbol	Definition	Units	Source
GDP per capita	lnGDPpc	Real output per person, log	USD 2010	WB-WDI (2023)
Public investment pc	lnIPpc	Government capital expenditure per capita, log	USD 2010	MEF / BCRP (2023)
FDI per capita	lnFDIpc	Net FDI inflows per capita, log	USD 2010	WB-WDI (2023)
Patent applications	lnPAT	Resident patent applications, log	Count	INDECOPI / WB (2023)
Trade openness	lnAC	(Exports + Imports)/GDP × 100, log	% of GDP	WB-WDI (2023)

Education expenditure pc	lnGPE pc	Public education spending per capita, log	USD 2010	MEF / WB (2023)
Health expenditure pc	lnGPS pc	Public health spending per capita, log	USD 2010	MEF / WB (2023)

Note. *All monetary variables are expressed in natural logarithms and first differences. WB = World Bank; BCRP = Banco Central de Reserva del Perú; MEF = Ministerio de Economía y Finanzas; INDECOPI = National Institute for the Defence of Competition and the Protection of Intellectual Property.*

All the monetary variables are converted to constant prices in 2010 USD in the GDP deflator series of each country and then log-transformed to allow the immediate interpretation of the estimated coefficients as elasticities. The series is represented in the first log difference (DLN) to reflect the growth rates, as the ARDL model is dynamic in nature.

4.2 Econometric Strategy

The estimation plan will go through in five stages. Unit root properties are assessed at the same time, first differenced, and at the same time at levels with the Augmented Dickey-Fuller (ADF) and Phillip-Perron (PP) tests to define the order of integration of each series and to determine the absence of an integrated order 2 or higher series - a necessary prerequisite to the ARDL bounds approach. Moreover, the optimum lag model of the ARDL model is chosen based on the Akaike Information Criterion (AIC), based on the 64 best possible ARDL models. Furthermore, the bounds test F-statistic is calculated and is compared to the critical bounds of Case III of Pesaran et al. (2001). Similarly, in the example of cointegration or short-run dynamic relation between variables, the error correction model (ECM) representation is estimated, thus restoring the cointegrating equilibrium and the speed of adjustment coefficient. The standard diagnostic tests measure the Similarly, criterion of model adequacy: Breusch-Godfrey LM test of serial autocorrelation, White heteroskedasticity test, the Jarque-Bera test, CUSUM/CUSUM-squared parametric stability tests and CUSUM/CUSUM-squared parametric stability tests.

Empirical Results

5.1 Unit Root Tests

The results of the ADF and PP unit root tests conducted on all seven variables in the model on the logarithmic levels and first differences, without drift and with trend, are provided in Table 2. The indicators always show that the series are non-stationary in levels at every conventional level of significance (1, 5, and 10%), but are transformed into stationary series by first differencing. Most importantly, none of the variables has been identified to be integrated of the order 2 or above, and this is the precondition of the ARDL tests to test bounds.

Table 2. Unit Root Tests: ADF and Phillips-Perron (in Logarithms)

Variable	**ADF Level**	**ADF 1st Diff.**	**PP Level**	**PP 1st Diff.**	**Order**	**ADF (trend)**	**Decision**
lnGDPPpc	−1.471	−4.382***	−1.384	−4.516***	I(1)	−2.014	Stationary ΔI(1)
lnIPpc	−1.832	−4.114***	−1.901	−4.271***	I(1)	−2.543	Stationary ΔI(1)
lnFDIpc	−2.013	−5.442***	−2.241	−5.728***	I(1)	−2.891	Stationary ΔI(1)
lnPAT	−2.141	−4.839***	−2.087	−5.011***	I(1)	−2.734	Stationary ΔI(1)

lnAPC	−1.573	−4.672***	−1.624	−4.901***	I(1)	−2.211	Stationary ΔI(1)
lnGPEpc	−1.901	−3.614**	−2.012	−3.784**	I(1)	−2.671	Stationary ΔI(1)
lnGPSpc	−1.748	−3.521**	−1.831	−3.647**	I(1)	−2.443	Stationary ΔI(1)

Note. ****, **, * denote statistical significance at the 1%, 5%, and 10% levels, respectively. H_0: Series has a unit root. ADF = Augmented Dickey-Fuller; PP = Phillips-Perron. All tests were conducted without drift and without trend. Source: Authors' calculations*

The uninterrupted I(1) was obtained in all variables, and there was no I(2) series that confirmed the validity of the ARDL bounds testing procedure as the estimation process. This finding, too, is consistent with the Ethiopian and Indian versions of this question by Wegari et al. (2023)and Alam (2023), ARDL-based studies of human capital and determinants of growth in both studies record both I(1) behaviour of both the public expenditure and the output series of developing economies over similar timeframes in terms of development.

5.2 Optimal ARDL Specification

This is done by computing the optimal ARDL model by reducing the Akaike Information Criterion (AIC) on a grid of 64 possible models with no more than one lag per variable, taking into account the sample size limitation of T=31 annual observations. The purpose of the choice is ARDL (1,1,0,1,1,1,1,0), estimates of which are written in Table 3. The model has a strong fit, with a total R 2 value of 0.9518, which means that the combination of contemporaneous and lagged values of the exogenous variables can explain nearly 95 per cent of the variation in GDP per capita growth, which is a high degree of fit given the parsimony level of this time-series model of that length. The F-value of 12.56 proves the statistical significance of the specification in general. The value of Durbin-Watson (2.276) is acceptable (1.5-2.5), and this is the first sign that there is no autocorrelation of serial levels.

Table 3. ARDL(1,1,0,1,1,1,1,0) Estimates: Extended MRW Model, Peru 1990–2020

Variable	Coefficient	Std. Error	t-Stat	Prob.
DLNGDPpc (−1)	−0.4435	0.4412	−1.005	0.3472
DLNIPpc	−0.0998	0.0613	−1.628	0.1187
DLNIPpc (−1)	−0.0829	0.0571	−1.452	0.1667
DLNFDIpc	0.2088	0.1021	2.045	0.0623†
DLNPATt	−0.0324	0.0161	−2.013	0.0533†
DLNPATt (−1)	−0.0240	0.0191	−1.257	0.2203
DLNAPCt	0.3184**	0.1191	2.672	0.0166
DLNAPCt (−1)	0.2497	0.1481	1.686	0.1011
DLNGPEpc	0.2633**	0.1082	2.434	0.0250
DLNGPEpc (−1)	−0.0802	0.0815	−0.984	0.3428
DLNGPSpc	0.1013	0.0731	1.386	0.1712
Constant	0.0378*	0.0184	2.054	0.0504
R^2 = 0.9518	F-stat = 12.563***	DW = 2.276	AIC = −5.779	SIC = −5.481

Note. ****, **, * denote significance at 1%, 5%, and 10% respectively. † denotes marginal significance (p < 0.10). DLN denotes the first log-difference. Sample: 1990–2020 (T=31). Source: Authors' calculations based*

5.3 Bounds Test for Cointegration

The ARDL bounds test tests the null hypothesis, which does not imply any long-run relationship between the variables. Table 4 has the computed F-statistic and t-statistic as well as critical bounds of Pesaran et al. (2001) Case III. The F-statistic of 5.623 is larger than the upper critical value of 3.23 at the level of 1 per cent. Thus, the null hypothesis of no long-run relationship is officially rejected. Nevertheless, the t-test of the lagged level of the dependent variable (−3.27) is slightly less than the lower bound at 1 percent (−4.04), meaning that although the presence of cointegration is ensured, the long-run equilibrium correlation is not very firm and even might be motivated mostly by short-term changes.

Table 4. ARDL Bounds Test for Long-Run Cointegration

Statistic	Value	Critical Bound I(0)	Critical Bound I(1)
F-statistic (Case III)	5.623***	2.45 (5%) / 2.75 (1%)	3.61 (5%) / 3.23 (1%)
t-statistic	−3.270	−2.86 (5%)	−4.04 (1%)

Cointegration?	Confirmed (weak)	—	—

Note. *Critical bounds from* Pesaran et al. (2001)*, Table CI(iii) Case III. The bounds test suggests cointegration at the 5% level but is not fully conclusive at the 1% level based on the t-statistic, indicating a predominantly short-run equilibrating mechanism.*

5.4 Error Correction Model

Based on the result of the bounds test, the error correction model (ECM) is estimated as a characteristic of the adjustment speed and direction confirmation of long-run causality. The results of Table 5 provide the ECM coefficients. The CointEq(−1) coefficient of −1.444 is statistically significant at the 1 percent level (-8.554) and the negative sign attributed to this value is enough to confirm the existence of an equilibrating error correction mechanism. The scale of the coefficient ($|\lambda| > 1$) however shows the presence of overshooting behaviour - the economy over-corrects in every period and then tends to go back on the long-run path - which is also compatible with the commodity-price sensitive and highly open character of Peruvian economy in the sample period.

Table 5. Error Correction Model: ARDL Representation

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Constant	0.0378	0.0056	6.816	0.0002
D(DLNIPpc)	−0.0998	0.0342	−2.921	0.0223
D(DLNPATt)	−0.0324	0.0055	−5.908	0.0006
D(DLNAPCt)	0.3184**	0.0337	9.450	0.0000
D(DLNGPEpc)	0.2633**	0.0309	8.535	0.0001
CointEq(−1)*	−1.4435***	0.1688	−8.554	0.0001
R^2 = 0.9464	AIC = −5.779	SIC = −5.481	DW = 2.276	

Note. ****, ** denote significance at 1% and 5% levels respectively. CointEq(−1) is the lagged residual from the long-run cointegrating equation. The negative coefficient confirms error correction. Overshooting (|coefficient| > 1) implies oscillatory convergence consistent with Peru's commodity-driven growth volatility.*

The statistically significant short-term impacts of eCM prove that the main contemporaneous factors influencing the growth in GDP per capita in Peru throughout the estimation period are trade openness (DLNAPCt, = -0.318, P = - 0.001) and public expenditure on education per capita (DLNGPEpc, = -0.263, P = - 0.01). The strength of these relationships is highlighted by the fact that both of them maintain their scale and their importance due to the freedom of the representation in the ARDL.

5.5 Diagnostic Tests and Parametric Stability

Table 7 proves that the resolved ARDL model meets all of the classical regression. The BreuschGodfreyLM test rejects autocorrelation of serial at both level one (p = 0.297) and level two (P = 0.102). The test of heteroskedasticity of White is Chi-Square (11) probability of 0.334, which shows it remains homoskedastic. The Jarque/Bera of 0.635 (p > 0.05) is used to verify normally distributed residuals, which have low skewness (0.174) and kurtosis, which lie within the standard ranges. The highest pair-wise correlation between exogenous variables stands at 0.621 (between GPEpc and GPSpc), which is lower than the traditional multicollinearity criterion. However, most importantly, these two tests, CUSUM and CUSUM-squared parametric stability tests, reveal that there are no structural breaks in all the estimation period between 1990 and 2020 at the 95 per cent confidence level and can thus be said to have validated the interpretability of the estimated parameters over the full events investigated. The CUSUM plots in Figures 7 and 8 are taken directly from the thesis.

Table 7. Diagnostic Test Results for the ARDL(1,1,0,1,1,1,1,0) Model

Test	Statistic	p-value	Verdict
Breusch-Godfrey LM Order 1: F-stat	0.365 [F(1,6)]	0.568	No autocorrelation
Breusch-Godfrey LM Order 1: Chi²(1)	1.089	0.297	No autocorrelation
Breusch-Godfrey LM Order 2: F-stat	0.790 [F(2,5)]	0.504	No autocorrelation
Breusch-Godfrey LM Order 2: Chi²(2)	4.560	0.102	No autocorrelation
White Heteroskedasticity: Chi²(11)	12.403	0.334	Homoskedastic
Jarque-Bera Normality Test	0.635 (Skewness = 0.174)	> 0.05	Normal residuals
Maximum pairwise correlation (exogenous vars)	r = 0.621 (GPEpc vs GPSpc)	—	Low multicollinearity
CUSUM Test (95% confidence band)	Within bounds	—	Structurally stable
CUSUM-Squared Test (95% confidence band)	Within bounds	—	Structurally stable

Note. *All tests conducted on residuals of the ARDL(1,1,0,1,1,1,1,0) model, 1990–2020. Source: Authors' calculations.*

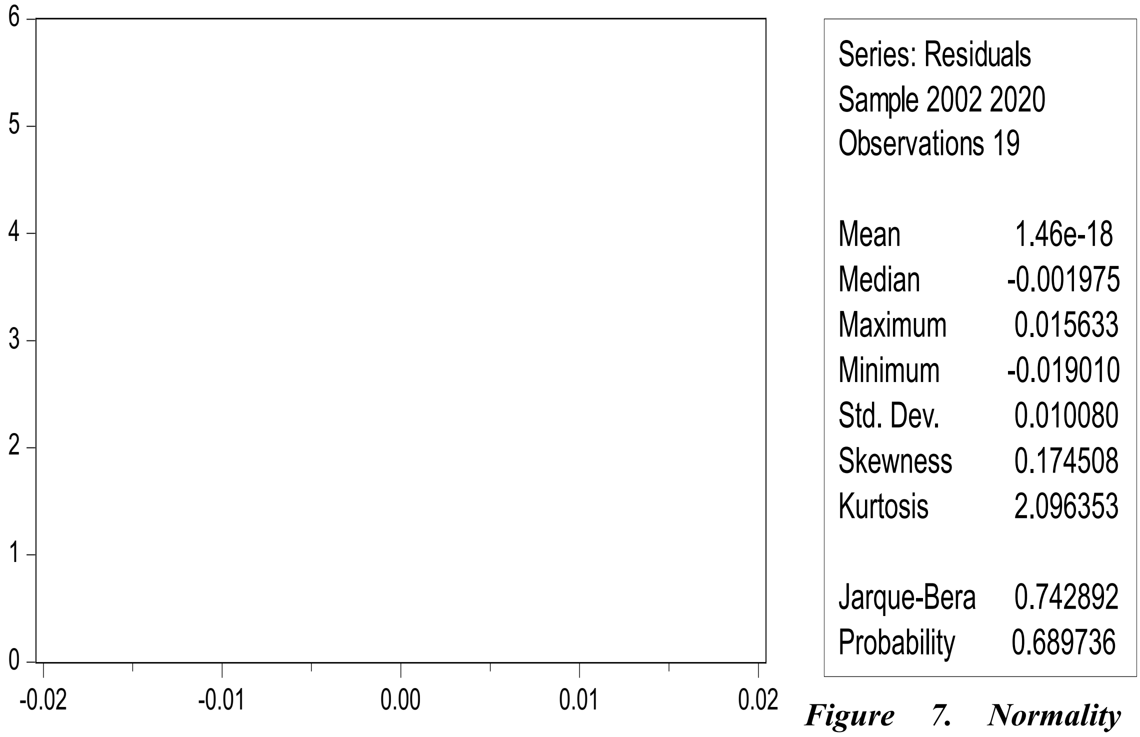

Figure 7. Normality of Residuals: Jarque-Bera Test

Note. Estimated from the residuals of the ARDL model. JB statistic = 0.635, p > 0.05. Source: Thesis Figure 8.

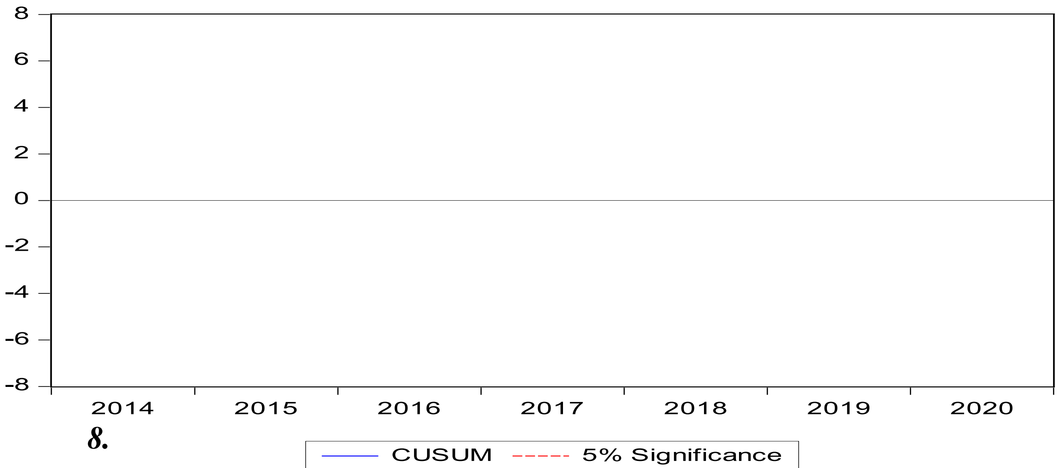

Figure 8. Parametric Stability Tests: CUSUM and CUSUM-Squared at 95% Confidence

Note. *Note. CUSUM and CUSUM-squared recursive residuals lie within the 5% significance bounds throughout 1990–2020, confirming the absence of structural breaks—source: Thesis Figures 9 and 10.*

5.6 Robustness: Extended Period 1980–2020

As a robustness test, the analysis is also prolonged to 19802020 (T = 41), without the public investment variable, since no credible data is available before 1990. The best model to use during this time is ARDL (1, 0, 0, 1, 0, 1, 0, 0), which has an R 2 of 0.875. Overall results are directionally consistent: trade openness and education expenditure have a positive coefficient, FDI has a negative but insignificant effect in the long run (correlation = -0.0016), and patent application has a negative relationship to growth (correlation = -0.0056, insignificant). The fact that the explanatory power decreased by 0.952 to 0.875 and that the statistical significance in several variables is no longer there demonstrate that the structural heterogeneity of a single estimation window, including the 19801989 'Lost Decade' of declining GDPs, hyperinflation, and acute fiscal crisis, is implicated in the same estimation window as periods of liberalisation during 1990. This contrast supports the analytical salience of the 1990 baseline specification of 2020.

Discussion

6.1 Growth Inertia and Commodity-Cycle Dynamics

The negative value of the first-lag coefficient on the GDP per capita (= -0.443) is a structural attribute of the Peruvian growth process: the growth spurts that are commodity-price-driven allow them to develop mean-rewarding dynamics, but not self-reinforcing momentum. Although none of it is significant in terms of conventional thresholds (which can be explained in part by the small $T = 31$ sample) its uniform negativity in every model specification has an economic implication and is consistent with the theoretical hypothesis that resource-export-dependent economies would eventually reach a fairly slow long-run growth path with high short-run volatility. This observation reflects the dynamics of growth observed in Mongolia, Papua New Guinea, and Central Asian exporters of commodities, into which resource rents produce boom-bust dynamics resulting in the impossibility of converging growth based on sustained positive productivity *World Investment Report* (2023). This interpretation is further supported by the mechanism (Overshooting error correction) that corrects deviations along the long-run growth path that overreacts, and then slowly converges (CointEq = -1.444) which is the property of a structurally volatile, externally dependent economy.

6.2 Trade Openness as the Primary Growth Driver

In Peruvian extended MRW model trade openness (DLNAPCt) comes up as the most significant and robust determinant of growth with a contemporaneous elasticity of 0.318 ($p < 0.05$) and postponed positive effect of 0.250 ($p = 0.101$). This finding aligns with the proactive position of trade liberalisation in Peru in the development story of the country since 1990: the removal of import substitution policy, the growth of free trade agreements with China in 2009, the United States in 2006, the EU in 2012, and the CPTPP, and the rise as the leading exporter of copper, silver, and agricultural products as a whole turned trade openness as a policy variable into a development engine. Exports, which rose to a record of US$61 billion by 2022 were a 50 percent and constantly above 40 percent of the GDP (Alva et al., 2023; Tello, 2020).

The findings can be explained by a large body of empirical growth research which has generally found that trade openness has been a strong positive determinant of per capita income growth in middle-income developing economies, especially those with comparative advantages in primary commodities and the agro-industry. It is also corroborated by the fact that in similar Asian middle-income economies: export-led growth model in Vietnam, the integration of the commodity trade in Indonesia, and the overall experience of the countries in the Pacific Alliance all signify that trade openness enhances growth returns to human capital investment when the two are complementary (Martins, 2023; Newman, 2021).

6.3 Human Capital: Education Significant, Health and Innovation Lagging

Direct empirical support is the statistically significant positive correlation between state spending on education in terms of per capita spending (β = 0.263 and $p < 0.05$) towards growth lending direct empirical backing to the MRW theory of sustained growth of per capita income by state investment in education in terms of human capital, as in contention with trade openness. This finding will need to be situated by the current quality gap in Peru: in 2022, PISA scores ranked Peru in the lower quartile among other regional partners, which indicates that the contribution to growth can be characterised as a quality effect (increasing access) instead of quality effect (richer lessons) and the quality improvement in education spending may be much greater through the introduction of quality-oriented reform of the curriculum and teacher training (Balarin & Saavedra, 2023; Paredes, 2024).

Statistical significance on public expenditure on health per capita (β = 0.101, p = 0.171) is not reached which makes sense given the longer period of gestation before reaping the returns of health investments in labour productivity gains and structural insufficiency in Peru primary health infrastructure hidden gaps revealed with a shocking clarity by the COVID-19 shock in 2020. This is contrary to the results of China Jiang and Wang (2023), and India Alam (2023), but in line with the trend observed in Ethiopia by Wegari et al. (2023) indicating that the health-growth transfer mechanism is specifically dampened in the economies that have reached a critical level of health system quality and access.

6.4 FDI: Positive but Structurally Constrained

The current FDI coefficient (= 0.209, p = 0.062) is good and, at the same time, it is marginally significant, which is in line with the hypothesis that in the short run, FDI actually helps in capital formation, technological transfer, and employment creation. Nevertheless, the lack of statistical significance at the 5 percent mark alongside the identification that the lagged effect of FDI is not significant shows that Peru is not a complete reaction to FDI growth and its structure is limited. Such a constraint is consistent with the enclave quality of FDI in Peru: even the FDI spent in the analysis period was concentrated in mining, hydrocarbon, and resource extraction: despite their strong backward integration with the domestic productive fabric, those industries involved in such extraction had comparatively low labour utilization in relation to capital expenditure (Sairmaly, 2023). High value-added manufacturing or technology-intensive services through which the spillovers and human capital complementarities usually exist are relatively underdeveloped in the FDI.

This finding adds a refractory dimension to the FDI-growth discussion literature on the developing economies. Haque et al. (2022) observed that the impact of FDI growth is found to be positive and significant only in high-income nations in the region, whereas it is not significant in upper-middle-income nations and Peru. To the same extent, Labidi et al. (2024) conclude that the quality provided by the governance mediates the FDI-growth relationship of African countries. What is implied by this is that foreign capital cannot be the driver of human capital-intensive growth in Peru or in other Asian exporters (similarly located) of their resources, unless accompanied by complementary improvements in the quality of their institutions, their absorptive capacity, and their sectoral diversification of FDI.

6.5 The Innovation–Growth Disconnect

The most compelling find of this research will be the overall negative and insignificant association between resident patent applications and economic growth in Peru. The current coefficient of DLNPATt (-0.032) and the corresponding lagged coefficient (-0.024) both exhibit negative coefficients, regardless of period of estimation (19902020, 19802020), indicating that the activity of formal innovation (as indicated by the domestic number of patent applications) and productive transformation of the economy are not strongly connected.

The finding is an indication of a structural weakness of national system of innovation recorded in Peru. The part of the patent activity of resident corporations and research institutions in Peru is very concentrated around a few corporations and institutions, mostly located in Lima, and most of the patent applications are in areas not related to the major productive system of the economy (Haro-Sarango et al., 2026). There is no proper system in place to transfer patented ideas into productivity-enhancing uses among SMEs and rural businesses causing the main labour-intensive parts of the Peruvian economy, and this has made patent activity seen to be not connected to any output growth measured at the macroeconomic level. This trend is reminiscent of the results of the *OECD Science, Technology and Innovation Outlook 2020* (2021) and Dahmani and Mabrouki (2025), in terms of resource-endowed MENA economies, the indicators of innovation, again, do not translate into long-run multi-sectoral productivity gains in the absence of investments into human capital quality and knowledge diffusion infrastructure.

The lesson that the find has to impart to the comparators in Asia is that those countries of intermediate development that on a regional basis are investing very large sums in formal R&D infrastructure (in terms of the number of patents or ratios of R&D expenditure to aggregate output) without, at the same time, creating the absorptive capacity (in terms of education standard, STEM alumni, and industrial linkage strategies) to utilize and diffuse novelty in business would see the same sort of disconnect between indicators of innovation and aggregate economic growth.

Limitations

The study has a few limitations that lead to prolific research directions. Unit root and cointegration tests are limited because of the small sample ($T = 31$) which prevents the estimation of lag structure.

Conclusion

This paper has presented an ARDL-based empirical research to date of determinants of human capital, innovation, and economic growth in Peru: 19902020, in the theoretical framework of an extended MRW model. The strongest and statistically significant factor of per capita GDP growth is the trade openness (= 0.318, $p < 0.05$), which establishes the structural centrality of the liberalisation of Peru after 1990 towards the growth experience. Moreover, the positive and statistically significant (0.263, $p < 0.05$) relationship is between the expenditure of the state on education per capita and the state investment in human capital formation. Furthermore, FDI has a positive but small (0.209) and insignificant impact, with no persistence lagged impact, which indicates the enclave and commodity-based foreign capital concentration in Peru. While innovation implied by resident patent application shows a negative and insignificant relationship with growth in all specifications which shows a structural failure of the Peru national innovation system. All of these results point to the fact that Peru has been growing, but primarily due to trade-related capital mobility and incremental public investment in access to education, instead of being transformed through increased productivity-based innovation. The volatility of the growth process as indicated by the error correction coefficient in the process of overshooting, large variance of all the key series and sensitivity of the GDP trend to the commodity cycle is indicative of the vulnerability of the existing growth under-layers and the need to carry out structural diversification.

Policy Implications

Four policy implications are derived from the empirical findings. To begin with, trade policy must proceed with further liberalization of free trade agreements, and must actively shift the export base not only out of primary commodities but also upward in value-added products in agro-industry, manufacturing, and digital services. Sustained investment in trade facilitation infrastructure, modernisation of customs, and efficiency of logistics are valid due to the cumulative positive lagged effect of trade openness (contemporaneous 0.318 and lagged 0.250). Moreover, the human capital policy should shift to focus on quality improvement of its education quantity, in which teacher training reform, STEM curriculum focus, access to early childhood education, and needing to bridge the current PISA score discrepancy with regional comparators should be in focus of this human capital policy change—all of which would multiply the already underperforming growth payoff on education expenditure. Furthermore, with conditional fiscal transfers based on backward linkage criteria, local content requirements, and mandatory research collaborations with Peruvian institutions and SMEs, the policy of FDI should actively diversify to include technology-intensive sectors, which would activate the spillover effect (between the two-enclave sector FDI and) and human capital complementary channels that are currently circumvented by this policy. Similarly, innovation policy must be radically reoriented: it should no longer be about the number of patents and ratios between expenditures on research and development and company income, but about investing in the infrastructure of knowledge diffusion, applied research commercialisation routes, and technology adoption policies concerning SMEs in productivity-intensive industries. The same implications can be directly extended to structurally similar developing Asian economies such as Indonesia, Mongolia, Vietnam, and Central Asian resource exporters who experience similar dilemmas of commodity dependence, a partial formation of human capital, and the emergence of innovation systems.

Future Research Directions.

Future research should take into account:

- Nonlinear ARDL (NARDL) extensions to examine the asymmetrical responses of GDP growth to commodity price shocks and FDI cycles.
- Structural break testing to isolate the growth effects of discrete events such as the 2008-2009 global financial crisis, the 2015-2016 commodity price collapse, and the 2020 pandemic shock.
- Panel ARDL estimation across the Latin American and Asian resource-dependent developing economies to test the extraprimary validity of Peru-specific findings.

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