

DETERMINANTS OF INNOVATION IN DEVELOPING COUNTRIES: A PANEL DATA ANALYSIS

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ABSTRACT

The paper investigates how education, research and development expenditure, foreign direct investment, trade openness, infrastructure, institutional environment, and digital access determine innovation in 23 developing countries between 1996 and 2022. We applied a Fixed-Effects model with robust standard errors for panel data analysis, accounting for heteroskedasticity and autocorrelation. All variables were transformed into natural logarithms to facilitate the interpretation of elasticity. The findings indicate that education, R&D expenditure, FDI, trade openness, and strong institutions positively and significantly influence innovation. This study provides empirical evidence that digital access and infrastructure may inhibit rather than foster innovation when countries lack adequate absorptive capacity and institutional readiness.

Keywords: Innovation, Developing Countries, Panel Data

JEL Classification: O31, O33, O11, F21, I25

Article History:

Received : April 18, 2026

Revised : June 25, 2026

Accepted : July 20, 2026

Available online : July 31, 2026

I. INTRODUCTION

According to Novillo et al. (2022), innovation is the human ability to adapt to change and create solutions that address situations affecting one's quality of life or environment. With increasing productivity and the growing complexity of the modern economy, the role of innovation is no longer limited to social or individual settings but has become a crucial driver of economic development. Empirical studies confirm that innovation is seen as a dynamic driver of economic growth. The literature by Koc et al. (2025) shows that innovation activities positively affect a country's economic performance. Various studies have attempted to identify factors influencing a country's economic activity, with several determinants. In fact, bold, innovative decisions implemented can be relied upon as a key driver of economic growth.

To better understand the contribution of innovation to the economy, we can examine its role in economic transformation in developed countries. Developed countries generally have superior characteristics, including strong institutions, sophisticated infrastructure, and advanced technological capabilities (Bakari, 2024). Robust systems in developed countries have instilled the benefits of innovation. From a theoretical perspective, knowledge accumulation and long-term productivity increases are driven by innovation, a major catalyst for endogenous growth that ultimately results in sustainable economic growth (Romer, 1990). One reason why developed countries are able to optimally utilise innovation is the strong foundation of education and R&D investment that has been built. Education is an initial determinant of innovation activities, due to its significant role in generating knowledge, skills, and experience, which are key indicators of economic progress (Okolo et al., 2023). In their research, Okolo et al. (2023) emphasised that education has a strong positive effect on innovation and significantly influences economic growth, consistent with endogenous growth theory. Endogenous growth theory explains that education plays a crucial role in encouraging innovation (Pan et al., 2020). Other studies reinforce these findings and emphasise that higher education policy is an important factor in creating an innovative ecosystem (Hoareau et al., 2013).

In the same way, investment in research and development (R&D) has long been recognised as a factor driving innovation. Dritsaki & Dritsaki (2023) found that R&D investment has a significant impact on increasing innovation in European Union countries. In the long run, increased R&D spending can improve the Global Innovation Index (GII), but in the short run, it can have negative effects due to external factors such as the pandemic. This study confirms that R&D is a key driver of innovation in a country. Further empirical evidence indicates that investment in education and R&D is positively and significantly correlated with GDP per capita growth. Thus, the important role of human capital in driving innovation is reinforced (Le et al., 2024). The importance of innovation for economic development is increasingly recognised through foreign direct investment (FDI). According to research conducted by Le et al.

(2024), a 1% increase in total factor productivity (TFP) can increase economic growth by up to 9.3%. This result is consistent with Agrawal & Khan (2011), who state that foreign direct investment (FDI) has a positive and significant impact on economic growth, both as a source of capital formation and as a channel for the dissemination of technology and knowledge. Therefore, foreign direct investment (FDI) serves two purposes: it increases the innovation capacity of host countries and accelerates their economic transformation. However, increasing innovation in developing countries faces a number of structural problems. These include inadequate investment in education, research and development, inadequate infrastructure, and weak institutions. Absorptive capacity, or the ability to adopt and utilise technology and foreign direct investment, is also a key factor. Le et al. (2024) show that while FDI can boost productivity and growth, in developing countries, the results are often disappointing due to limited human capital and a lack of technological readiness. Furthermore, the digital divide and low internet penetration rates hinder technological progress.

Furthermore, these challenges not only hamper the adoption of new technologies but also create inconsistencies in empirical findings regarding the determinants of innovation in developing countries. External factors such as FDI, trade openness, infrastructure, and digital access can drive innovation when a country's structural conditions are favourable. One study shows that FDI, trade openness, GDP per capita, and R&D expenditure have a significant impact on technological innovation in BRICS countries (Ali et al., 2023). According to research by Tu (2024), there is a two-way relationship between innovation and foreign direct investment (FDI), where innovation drives investment, and FDI drives innovation. Furthermore, market size and labour force size have a significant impact on the attraction of foreign direct investment to developing countries. However, this is not entirely consistent with research by Le et al. (2020), which finds that the benefits of foreign direct investment (FDI) often fail to materialise in developing countries due to absorptive capacity constraints, low institutional quality, and outdated technology.

The misalignment of empirical results also affects digital access and infrastructure. According to S. Yang et al. (2025), the expansion and integration of infrastructure can create pathways for innovative mobility and knowledge transfer. Other research also provides empirical evidence of how infrastructure contributes to innovation growth. S. Yang et al. (2025) assessed the impact of the internet and high-speed rail (HSR) on urban innovation, and the results showed that both infrastructures increased the number of innovations. Conversely, Chen & Wang (2023) found that broadband speed (digital access) significantly drives patenting and innovation activity, more than internet penetration. These findings illustrate how advanced digital infrastructure can be a crucial catalyst for innovation. However, this situation is not fully reflected in many developing countries. Rapid digitalisation in developed countries and some large economies like China cannot be easily replicated,

as developing countries still face structural barriers, including poor network quality, uneven internet access, high service costs, and limited technology utilisation in the industrial sector. In developing countries, ICT infrastructure development and expansion of digital access still lag far behind those in developed countries, forcing governments to focus on catching up (Onitsuka et al., 2018). The concept of absorptive capacity, which argues that a nation's ability to recognise the value of external knowledge, assimilate it, and apply it productively determines the extent to which it benefits from new technology, helps explain this digital divide (Cohen & Levinthal, 1990).

Therefore, increased digital access may not lead to greater absorptive capacity and, consequently, may not generate the innovation gains observed in countries with more advanced digital ecosystems in the absence of adequate human capital, institutional support, and complementary infrastructure. This situation also demonstrates that a country's innovation challenges are not solely related to the technology itself, but also to the quality of education and institutional capacity that facilitates technology adoption and use. Numerous studies have shown that these two factors significantly impact a country's innovative activity. Quality institutions not only increase investor confidence but also accelerate the patent process and protect intellectual property rights (Danta & Rath, 2024). Poor governance can increase a company's risk of engaging in corrupt practices when pursuing financial innovation. In countries with weak governance and high levels of corruption, business actors often identify corruption as a major obstacle to innovation (Lee et al., 2020). Research by Lee et al. (2020) found that the innovation effect was significantly impaired in manufacturing firms operating in regions with poor governance or high levels of corruption.

Although previous research has emphasised the importance of education, FDI, trade openness, infrastructure, institutions, and digital access in fostering innovation, empirical evidence suggests that the relationships between these factors and innovation in developing countries are not always consistent. Some studies show that foreign direct investment (FDI) and investment growth significantly increase technology diffusion. However, other studies show that the benefits of FDI depend heavily on a country's absorptive capacity, institutional quality, technological advancement, and digital infrastructure. Consequently, while increased internet access and investment in digital infrastructure can stimulate innovation in developing countries, the effects are not always evident in countries still struggling with the digital divide, high service costs, and unreliable technology. This variation suggests that innovation in developing countries is a complex process that cannot be explained by a single factor but involves interactions among various structural elements.

However, previous studies have examined the drivers of innovation with a clear, focused approach, particularly in countries such as China and European countries. Consequently, there is still a lack of adequate empirical evidence on how

the determinants of innovation operate simultaneously in the context of developing countries with distinct characteristics and development constraints. In this context, this study makes a novel contribution through a more in-depth analysis. It not only views education as a key factor in developing innovation skills, but also examines R&D, foreign direct investment (FDI), infrastructure, institutions, trade openness, and digital access as interacting factors. Using panel data from 23 developing countries over 27 years and addressing heteroscedasticity and autocorrelation, this study provides a more comprehensive understanding of how these combined determinants operate and clarifies the structural conditions that strengthen or limit the influence of education on innovation.

Based on this framework, this study aims to analyse the influence of education and other supporting factors on innovation in developing countries and to assess how interactions among these variables can strengthen, weaken, or moderate the influence of education on a country's innovative capacity. Therefore, this study is expected to provide a more comprehensive understanding and more appropriate policy recommendations for developing countries to increase their innovation capacity and support the growth of knowledge-based economies.

II. LITERATURE REVIEW

Education is a crucial investment in human capital development and a key prerequisite for a country's capacity for innovation. These investments are important because they not only create a high-quality workforce but also foster an environment conducive to both radical and incremental innovation (Hanushek & Woessmann, 2020). According to Romer (1990), education is not merely a consumption good but rather a strategic investment in accumulating knowledge and skills that serve as essential inputs in the production process and enhance economic growth. Absorptive capacity refers to the ability to recognise, absorb, assimilate, and apply knowledge from external sources, such as imported knowledge or knowledge from FDI, to generate innovations suited to the domestic environment (Cohen & Levinthal, 1990). According to Sultanuzzaman et al. (2019), telephone subscriptions and technology have been shown to drive economic growth in developing Asian countries by increasing productivity and reducing transaction costs. However, the benefits of technology depend heavily on a country's human capital readiness, with education playing a central role.

Education plays a significant role in fostering innovation by enhancing innovative capacity, absorptive capacity, and knowledge diffusion. Higher and vocational education, in particular, plays a direct role in influencing innovation by preparing scientists, engineers, and technical personnel who are actively involved in innovation processes, research, and development (Romer, 1990). Graduates from this institution not only become technical workers, but also contribute to change by expanding the boundaries of knowledge through basic and applied research (Valero

& Van Reenen, 2019). At the same time, education increases absorptive capacity by producing an educated workforce capable of understanding, adapting, and developing foreign technology, thereby maximising the benefits of technology transfer (Benhabib & Spiegel, 1994). Without an adequate educational base, foreign technology transfers are often not effectively assimilated and do not significantly contribute to productivity growth within a country (Borensztein et al., 1998).

Sultanuzzaman et al. (2019) show that human capital, as measured by education, has a positive and significant effect on economic growth in developing Asian countries in both the short and long term. These findings support the theory that human capital accumulation increases individual productivity and generates knowledge spillovers that benefit the economy as a whole. Consequently, human capital accumulation serves as an engine of sustainable long-term growth (Hanushek & Woessmann, 2020). Furthermore, a strong education system facilitates the dissemination of knowledge and best practices across society and industry. This creates a supportive environment for innovation through alumni networks, scientific publications, and academic-industry collaborations. Educational institutions act as hubs in regional innovation ecosystems, known as the Triple Helix model, in which government, business, and academia mutually reinforce one another. However, this process does not occur naturally (Etzkowitz & Leydesdorff, 2000).

The positive relationship between education and innovation has been consistently supported by empirical evidence. Okolo et al. (2023) found that education has a strong positive impact on innovation and economic growth in various countries. Similarly, Pan et al. (2020) argue that improving the quality of education significantly accelerates the creation and adoption of new technologies. They emphasise that education not only develops cognitive skills but also enhances critical thinking and problem-solving abilities, which are essential for generating innovative ideas. Lam et al. (2022) explain this relationship in a study in Malaysia. In addition, Sultanuzzaman et al. (2019) show that technology and exports, supported by innovation capacity, contribute significantly to economic growth in emerging Asia. They found that innovation is a crucial factor in enhancing the impact of high-tech trade on economic growth. Overall, these findings suggest that without a strong foundation of human capital developed through education, countries may lack the capacity to innovate and fully benefit from high-tech trade opportunities. This aligns with previous findings showing that the level of education in a population may be a stronger determinant of national innovation capacity than R&D itself.

Skills are necessary for innovative activities. Without adequate education, a country will not be able to independently create, develop, and utilise new technologies through trade and foreign direct investment (FDI). Therefore, education acts as a driver, strengthening the influence of other components that drive innovation. According to Sultanuzzaman et al. (2019), technology adoption and export growth are highly dependent on domestic capacity, including human capital and education.

Therefore, education plays a crucial role as a lever or incentive that enhances the influence of other elements driving innovation. Lam et al. (2022) suggest that, when examining the dominance of multinational corporations (MNCs) in innovation activities in Malaysia, the absence of quality education leads to inefficiencies in R&D spending and limits the ability to capture knowledge spillovers from global partners (Borensztein et al., 1998). Ultimately, education is more than just an input; it is a critical infrastructure that enables all innovation mechanisms, from absorption, creation, to diffusion, to operate optimally to drive inclusive and sustainable economic growth (Hanushek & Woessmann, 2020).

2.1. Hypothesis

H1: Education level positively affects the level of innovation in developing countries (Benhabib & Spiegel, 1994; Okolo et al., 2023; Sultanuzzaman et al., 2019).

H2: Research and Development (R&D) investment positively affects innovation in developing countries (Dritsaki & Dritsaki, 2023; Ipinnaiye et al., 2025).

H3: Foreign Direct Investment (FDI) positively affects innovation in developing countries (Ali et al., 2023; Barboza et al., 2025; Agrawal, 2011; Tu, 2024).

H4: Trade openness positively affects innovation in developing countries (Arshad et al., 2023; Ali et al., 2023).

H5: Infrastructure has a positive effect on innovation in developing countries (Foster et al., 2023; Crescenzi et al., 2007; Osei, 2024; Onitsuka et al., 2018; Yang et al., 2025).

H6: Institutional quality positively affects innovation in developing countries (Danta & Rath, 2024).

H7: Digital access positively affects innovation in developing countries (Chen & Wang, 2023; Yang et al., 2025; Du & Wang, 2024).

III. METHODOLOGY

This study utilises unbalanced panel data. The data covers 23 developing countries. These countries were selected through a rigorous selection process based on the availability of complete and consistent core variable data from the World Bank and the World Intellectual Property Organisation from 1996 to 2022. Economically, these countries are categorised as middle-income countries by the World Bank. Beyond data availability, the selected countries represent several geographical regions, including Asia, Latin America, the Middle East, North Africa, and Eastern Europe. This regional diversity improves the representativeness of the sample and reduces the possibility that the findings primarily reflect the characteristics of a single geographic region. Nevertheless, the final sample remains constrained by the

availability of complete and consistent data for all variables throughout the study period. Furthermore, the selected countries exhibit varying levels of innovation capacity and socio-economic development, enabling the analysis to capture heterogeneous innovation dynamics across developing economies. All variables in this study were converted to natural logarithms ($\ln$) so that the regression coefficients could be interpreted as elasticities and to help stabilise the data variance. The period runs from 1996 to 2022.

The primary source of data for the research variables is the World Development Indicators. The indicator was published by the World Bank in 2023. Meanwhile, the innovation indicator data were obtained from the World Intellectual Property Organisation, which also released the same data in the same year (World Intellectual Property Organisation, 2023). The selection of the period from 1996 to 2022 has a specific reason. The late 1990s marked a crucial moment in the history of accelerated digitalisation. It also witnessed deeper global economic integration. This significantly impacted the dynamics of innovation in developing countries (Comin & Hobijn, 2004; Dedrick et al., 2013). This research period also encompassed several major, volatile economic events. For example, the 2008 global financial crisis. Then there was the COVID-19 pandemic, which significantly impacted foreign direct investment (FDI) flows, international trade patterns, and the diffusion of technology (Kose et al., 2022). 2022 was chosen as the research deadline. It's the most recent year with complete data. This data has been officially verified from the sources used in the study.

To comprehensively evaluate the impact of education, R&D, FDI, trade openness, institutional quality, infrastructure, and digital access on innovation in developing countries, this study develops a conceptual framework as shown in Figure 1. This model positions education as the primary variable influencing innovation, while the other six variables are treated as supporting factors that can strengthen or weaken innovation dynamics at the country level.

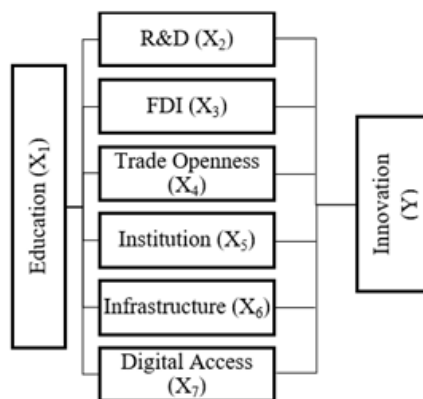


Figure 1. Conceptual Framework

The estimated mathematical model can be written as follows:

$$INOV_{it} = \alpha + \beta_1 EDU_{it} + \beta_2 R\&D_{it} + \beta_3 FDI_{it} + \beta_4 TRADE_{it} + \beta_5 INST_{it} + \beta_6 INFRA_{it} + \beta_7 DIGI_{it} + \mu_i + \varepsilon_{it}$$

where i denotes the country and t denotes the observation year. The component u_i represents fixed effects or individual effects specific to the country, namely, characteristics that do not change over the study period and can influence innovation, such as innovation culture, economic structure, or relatively stable governance quality. Meanwhile, it is an error term that captures random disturbances within each country and year. The addition of individual effects u_i ensures that the coefficient estimates β are not biased by correlations between the independent variables and fixed characteristics of a country, making the Fixed Effects model the most appropriate approach for this study.

To obtain consistent estimates, this study employs a panel-data-based econometric approach. Because the sample comprises 23 countries spanning 27 years, individual country characteristics may differ and systematically influence innovation. Therefore, the initial analysis used Pooled Ordinary Least Squares (OLS) regression as the baseline model. Next, a Chow test was conducted to determine whether the Fixed Effects (FE) model was more appropriate than the OLS model. The test results indicate that the FE model is more appropriate because cross-country characteristics remain constant over time (Liu, 2002; Shera et al., 2014). Model selection was then followed by a Hausman test to determine whether the FE model was superior to the Random Effects (RE) model. The test results showed that country-specific effects were correlated with the explanatory variables; the Fixed Effects model was therefore selected as the primary estimation method for this study.

In classical assumption testing, heteroscedasticity and autocorrelation were found in the FE model. These conditions can compromise the accuracy of standard errors, leading to misleading significance tests. To address this, robust standard errors are used to ensure that coefficients remain consistent even when error variances are heterogeneous (Brambor et al., 2013). In addition, all quantitative variables were transformed into natural logarithms to equalise the scale between variables, reduce skewness, and allow interpretation of elasticity. For variables with zero or negative values, adjustments were made before the logarithmic transformation to avoid undefined results. Considering all these test results, the selection of FE based on the Chow and Hausman tests, the absence of multicollinearity, and robust adjustments for heteroscedasticity and autocorrelation, the FE model with robust standard errors was deemed the most appropriate and reliable for this study.

IV. RESULTS AND ANALYSIS

The descriptive statistics of each variable in the model are presented in Table 1. The average of the INOV variable, measured by the number of patents, is 1.97 with a standard deviation of 1.48, which is relatively lower than the research Okolo et al. (2023) , with a mean of 9.19 and a standard deviation of 1.88. This difference in standard deviation indicates that the innovation data in this study sample not only has a lower mean but also a narrower distribution than in previous studies. In other words, the variation in the number of patents across countries in this study is smaller, indicating greater homogeneity of innovation in the study sample. This condition allows the analysis of factors influencing innovation to focus more on the main determinants, without being overly influenced by countries with extreme patent numbers.

The education variable (EDU) has an average of 2.07 with a standard deviation of 0.26, reflecting a relatively uniform average length of schooling across countries, while research and development investment (RD) has an average of 7.85 with a standard deviation of 1.76 and a range of 4.04-12.24, indicating a gap in R&D capacity between countries that can affect innovation capabilities. The level of trade openness (TRADE) has an average of 3.36 with a standard deviation of 0.53, indicating a relatively homogeneous level of openness, while digitalisation (DIGI) has an average of 2.48 with a standard deviation of 2.24 and a range of -8.91 to 13.46, indicating significant inequality in the adoption of digital technology. Infrastructure (INFRA) averaged 4.28 with a standard deviation of 1.12 and a range of 1.86-7.17, indicating that most countries have adequate infrastructure capacity, although some countries still have limited facilities. FDI averaged 1.62 with a standard deviation of 0.41 and a range of -3.16 to 2.54, indicating fluctuating foreign investment flows. Institutions (INSTA), measured by the Corruption Perceptions Index, averaged 0.21, with a standard deviation of 0.53 and a range of -5.85 to 1.17, indicating variation in institutional quality across countries. Descriptive statistics show that the study sample has diverse characteristics in terms of innovation, education, R&D, trade, digitalisation, infrastructure, FDI, and institutions. This variation provides an important basis for analysing factors influencing innovation, while emphasising the need for policy strategies tailored to the specific conditions of each country, taking into account the relatively low level of innovation and variations in existing resource capacity.

Table 1. Descriptive Statistical Analysis

Variables	Obs	Mean	Std. dev.	Min	Max
InNOV	617	1.97	1.48	-2.30	5.35
InEDU	617	2.07	0.28	1.02	2.55
InRD	617	7.85	1.76	4.04	12.24
InTRADE	617	3.36	0.53	1.91	4.80

InDIGI	617	2.48	2.24	-8.91	13.45
InINFRA	617	4.28	1.12	1.86	7.17
InFDI	617	1.62	0.41	-3.16	2.54
InINSTA	617	0.21	0.53	-5.85	1.17

Source: Data Processed

Table 2 presents a correlation matrix among all research variables, depicting the initial relationships between education (EDU), R&D, FDI, trade openness (TRADE), institutional quality (INST), infrastructure (INFRA), digital access (DIGI), and innovation (INOV). The Pearson correlation results show that InEDU and InINOV are correlated at 0.52, while InRD and InINOV are correlated at 0.56. These values indicate that improvements in educational quality and R&D intensity are associated with increased innovation capacity in developing countries. These findings align with endogenous growth theory, which positions education and R&D as the primary foundations for human capital formation and innovative capacity (Romer, 1990). Empirically, this relationship is consistent with studies Atsu & Adams (2023) that investment in quality education is not only important for developed countries but also relevant to driving innovation in developing countries. The consistency of these results compared to studies in OECD countries suggests that improving human skills and capabilities is a universal factor in spurring innovative activity, although the scale may vary across country groups. Furthermore, digitalisation (InDIGI) also shows a positive correlation with innovation, with a value of 0.36, indicating that the development of digital technology contributes to increased innovation activity, although with a weaker relationship than education and R&D. These results reflect that increased digital connectivity enables faster information dissemination, expands research capabilities, and supports digital transformation. These findings align with evidence from Chen & Wang (2023) which shows that digital connectivity can increase innovation output.

Furthermore, trade openness (InTRADE) and FDI (InFDI) variables have weaker correlations with innovation, at 0.18 and 0.15, respectively, indicating that economic openness contributes to innovation but is not a dominant factor in the sample of developing countries. Unlike the other variables, infrastructure (InINFRA) shows a negative correlation with innovation, with a value of -0.36. This negative relationship may reflect variations in development levels across developing countries, where countries with relatively lower infrastructure may exhibit rapid innovation growth due to ongoing technology adoption or intensive structural reforms. However, this interpretation requires further analysis using regression models, as correlation does not imply a causal relationship. Meanwhile, the institutional quality variable, as measured by the corruption perception index (InINSTA), shows a positive correlation with innovation of 0.25. This indicates that countries with lower levels of corruption tend to have higher levels of innovation. In other words, a cleaner and more

accountable institutional environment provides more conducive conditions for innovative activity, for example, through regulatory certainty, bureaucratic efficiency, and minimal distortion in resource allocation. However, the influence of institutions on innovation varies with a country's innovation capacity. Sharma et al. (2022) explains that in less innovative countries, overly strict institutions can hinder technological learning, whereas in developed countries, strong institutions are the main drivers of increased innovation.

Table 2. Correlation Matrix

	InNOV	InRD	InEDU	InTRADE	InDIGI	InINFRA	InFDI
InNOV	1.00						
InRD	0.56	1.00					
InEDU	0.52	0.02	1.00				
InTRADE	0.18	0.12	0.28	1.00			
InDIGI	0.36	0.39	0.48	0.19	1.00		
InINFRA	-0.36	0.00	-0.35	0.08	0.19	1.00	
InFDI	0.15	-0.07	0.16	0.19	0.17	-0.19	1.00
InINSTA	0.25	-0.04	0.18	0.14	0.25	-0.46	0.31

Source: Data Processed

The variables education, R&D, institutions, trade openness, FDI, and digitalisation all demonstrate relationships consistent with their role in driving innovation in developing countries. Meanwhile, the negative relationship between infrastructure and the economy suggests structural dynamics that warrant further study. These findings provide a preliminary basis for suggesting that innovation does not stem from a single factor but rather results from a systemic interaction between the quality of human capital, institutional effectiveness, technological development, and global economic connectivity. Therefore, developing countries need to simultaneously promote improvements across multiple sectors to create a more comprehensive innovation ecosystem.

Correlations between other independent variables range from low to moderate, with the highest value recorded between education and digitalisation at 0.48. No correlations between variables approach 0.80, indicating no serious multicollinearity in the research model. Overall, this correlation pattern indicates a relationship direction that largely aligns with theoretical expectations and previous empirical findings.

The regression results highlight the complex relationships among factors influencing innovation in developing countries. Education level (InEDU) has a positive and significant effect on innovation. A 1% increase in education level will increase innovation by 0.56%. This research aligns with capital theory from Romer (1990)

regarding the importance of education as a foundation for innovation capacity. Furthermore, research and development (R&D) expenditure has a significant impact on innovation. With a coefficient of 2.45 ($p = 0.00$), a 1% increase in R&D expenditure will increase innovation by 2.45%. This is in line with the theme of the OECD Science, Technology and Innovation Outlook (2021) that investment in research and development directly increases innovation output. In general, trade (InTRADE) and foreign direct investment (InFDI) have positive impacts (coefficients of 0.46 and 0.27, respectively), confirming the existence of technological spillovers through global integration, as explained by Borensztein et al. (1998).

Table 3. Regression Result

Linear regression	Number of obs	=	617
	F(7,609)	=	178.54
	Prob F	=	0.00
	R-squared	=	0.68
	Root MSE	=	0.83

InNOV	Coefficient	Robust Std. Err.	t	p> t >	[95% conf. Interval]	
InRD	2.45	0.21	11.52	(0.00)***	2.03	2.87
InEDU	0.56	0.02	24.80	(0.00)***	0.52	0.60
InTRADE	0.46	0.07	7.01	(0.00)***	0.33	0.59
InDIGI	-0.16	0.02	-6.44	(0.00)***	-0.20	-0.11
InINFRA	-0.26	0.04	-6.25	(0.00)***	-0.34	-0.18
InFDI	0.27	0.09	3.08	(0.02)**	0.10	0.44
InINSTA	0.32	0.10	3.18	(0.02)**	0.12	0.51
_cons	-8.09	0.56	-14.57	(0.00)***	-9.18	-7.00

Note: *** p < 0.01, ** p < 0.05, * p < 0.10

Source: Data Processed

However, contrary to H5 and H7, the estimated digital access (InDIGI) and infrastructure (InINFRA) variables showed significant negative effects on innovation, with coefficients of -0.16 and -0.26, respectively. Therefore, H5 and H7 are not supported. These findings differ from the initial hypotheses and previous studies, which generally argue that digitalisation and infrastructure promote innovation (Calderón & Servén, 2014; Chen & Wang, 2023; Yang et al., 2025). One possible explanation draws on Hargittai's (2002) concept of the "second-order digital divide," which distinguishes between first-order inequalities in physical access and second-

order inequalities rooted in differences in people's skills and abilities to use digital technology effectively. In other words, expanding access to digital content does not automatically translate into productive use; without adequate digital skills and capabilities, such access can actually widen the digital divide rather than narrow it.

Similarly, the negative coefficient of infrastructure suggests that infrastructure investment alone does not necessarily stimulate innovation. In developing countries, the effectiveness of infrastructure depends not only on the amount of investment but also on the quality and efficiency of public investment. As argued by Chakraborty and Dabla-Norris (2009), public investment contributes to productivity and growth only when supported by efficient allocation, effective implementation, and strong institutional oversight. Therefore, poorly planned or inefficiently managed infrastructure may fail to generate innovation outcomes despite substantial investment. Conversely, a significant positive contribution was obtained from institutional quality (InINSTA) (coefficient = 0.32; $p = 0.02$). This is in line with the notion of Acemoglu et al. (2004) that strong institutions such as intellectual property rights protection, clean governance, and a supportive legal framework are key to a healthy innovation ecosystem.

This robust regression model has good explanatory power, with an R-squared of 0.68, indicating that approximately 68% of the variation in innovation is explained by the variables included in the model. The root mean squared error (RMSE) of 0.83 indicates that the average deviation between the predicted and observed innovation values is relatively small, suggesting satisfactory predictive accuracy. The statistical results are also robust, as indicated by the F-statistic of 178.54 ($p < 0.01$). The negative and significant constant ($\beta_0 = -8.09$, $p < 0.01$) reflects the intercept of the log-log specification. Because all explanatory variables are expressed in natural logarithms, a value of zero on the logarithmic scale corresponds to an original value of one for each explanatory variable, a situation that does not occur within the observed sample. Therefore, the intercept should not be interpreted as a realistic economic scenario but rather as a baseline parameter of the regression model. Nevertheless, its large negative magnitude suggests that innovation in developing countries does not emerge automatically in the absence of favourable explanatory conditions. Instead, higher levels of innovation depend on the combined contribution of factors such as R&D investment, education, institutional quality, trade openness, and foreign direct investment. This interpretation is consistent with the absorptive capacity perspective proposed by Cohen and Levinthal (1990), which emphasises that external knowledge can only be transformed into innovation when supported by sufficient internal capabilities.

This suggests that long-established factors, such as education and R&D, remain key. However, the situation in developing countries complicates the dynamics of innovation. The robust estimation method used strengthens the validity of our findings by addressing potential heteroscedasticity. Therefore, our reported results

are more reliable. Compared with previous research, unique contextual nuances are evident. Traditional factors such as education and R&D remain consistent with previous research. Meanwhile, supporting factors such as digitalisation and infrastructure show a negative relationship, contrary to general research findings. This situation suggests that not all supporting factors automatically contribute positively to innovation in developing countries. Everything depends on the quality of their implementation. Furthermore, the readiness of the overall innovation ecosystem also plays a significant role. From this, it can be concluded that a holistic and integrated approach is needed in policy, including resource allocation that considers not only quantity but also quality and the interrelationships among factors. Education and R&D must remain priorities, while digital and infrastructure development must be tailored to local innovation capacity and supported by strong institutions. In other words, the success of innovation is determined not only by the availability of inputs but also by how those inputs are integrated. The process of utilising them must be carried out within a harmonious innovation system. These systems must also support each other.

V. CONCLUSION AND RECOMMENDATION

Based on the study's results, education and research and development (R&D) activities are the main drivers of innovation in developing countries. Other supporting factors include openness in trade, foreign direct investment (FDI), and good institutional quality. However, digital access and infrastructure conditions have a negative impact, indicating that investment in physical assets and technology alone is insufficient without the ability to use them and adequate system readiness. These findings emphasise that policies must be integrated, focusing not only on improving resources but also on strengthening the innovation ecosystem as a whole. This includes improving the quality of education, strengthening R&D, reforming institutional systems, and implementing inclusive, tailored digital and infrastructure strategies aligned with local capacity needs.

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