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Nexus between technological innovation, trade, education and institutional quality: Evidence from dynamic SUR estimation

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Abstract

This study analyzes the various factors that promote technological advancement in lower-income nations. Additionally, it aims to provide policy recommendations that can effectively stimulate and nurture such advancements. The study employs a robust methodology, which includes the utilization of a comprehensive dataset and the application of rigorous statistical analysis techniques. A thorough examination of the current body of literature supports the foundation of this work. The study uncovers a noteworthy positive correlation among institutional quality, trade openness, and education about technological innovation. The statement implies that countries with stronger institutions create a favorable environment for the growth and progress of innovative practices. The study further emphasizes the positive influence of both domestic and international trade on the innovation process. Moreover, it emphasizes the positive influence of education on technological advancement, underscoring the importance of accessible and high-quality education in fostering innovation. Based on the empirical evidence presented in this study, it is recommended that policymakers give significant priority to the implementation of institutional reforms, facilitation of trade integration, and allocation of resources towards education. These measures are crucial for stimulating and nurturing technological advancements within lower-income nations. The study provides valuable insights that can benefit policymakers and practitioners promoting innovation-driven development in lower-income countries. Nevertheless, it is crucial to consider alternative explanations and contextual factors that may impact the interaction between these variables.

Keywords: Technological innovation; Trade openness; Institutional Quality; Dynamic; Seemingly Uncorrelated Regression

1. Introduction

The importance of environmental conservation has significantly increased recently due to the escalating effects of climate change. Technological innovation and institutional quality are pivotal in effectively addressing environmental concerns and promoting sustainable behaviors. This essay explores the importance of these two factors in promoting positive change and achieving environmental sustainability [1-6]. Technological innovation is crucial in mitigating environmental issues by identifying new products, improving existing processes, and optimizing organizational systems. Technological innovation is crucial in preserving the environment by reducing energy consumption, mitigating pollutant emissions, and promoting a sustainable economy. Recent research has underscored the crucial significance of technological innovation in driving industrial transformation, augmenting operational efficiency, and facilitating economic restructuring. Technological innovation related to the environment is emerging as a powerful tool with significant positive impacts on the natural environment. These advancements greatly contribute to promoting sustainable development through efficient utilization of green energy sources and reducing reliance on fossil fuels. In addition, they assist countries in optimizing manufacturing processes and enhancing overall efficiency. Technological

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innovation plays a pivotal role in the mitigation of climate change, the promotion of sustainable economic development, and the reduction of carbon dioxide emissions. In addition to technical enhancements, the effectiveness of institutions also exerts significant influence on endeavors aimed at environmental protection. Strong institutional frameworks play a vital role in tackling corruption, upholding the principles of the rule of law, minimizing military involvement in political matters, and improving the efficiency of public financial management. Robust institutional frameworks of high quality are of utmost importance for effectively implementing environmental governance policies and programs designed to regulate and mitigate pollution.

On the contrary, insufficient institutional quality can lead to long-lasting detrimental impacts on a country's economy. The quality of institutions directly influences the policies implemented by a country's institutions to cultivate cultural and legal frameworks that facilitate socioeconomic and financial activity. These constructions are intricately linked to efforts focused on mitigating environmental contamination. High-quality establishments positively impact the environment and lead to increased financial earnings by reducing the expenses associated with economic development. Adopting stringent institutional regulations and a robust legal framework may incentivize firms to decrease carbon dioxide (CO_2) emissions, promoting sustainable practices.

Technological innovation and institutional quality play pivotal roles in shaping the outcomes of environmental conservation efforts. Technological advancements enable the seamless integration of environmentally sustainable practices, leading to a notable reduction in energy consumption and a significant decrease in emissions of harmful pollutants. Meanwhile, robust institutional frameworks have been established to formulate policies and develop mechanisms that foster sustainable behaviors and mitigate the pollution. The importance of these elements cannot be emphasized enough in the endeavor to achieve environmental sustainability and address the challenges posed by climate change. By strategically allocating resources towards technological advancements and enhancing institutional frameworks, civilizations can potentially cultivate a future that is both environmentally conscious and sustainable [7]. Education, industry, and commercial growth are just a few examples of human pursuits that need constant innovation to succeed in the long run. Innovation was first used by Schumpeter [2]. He added that manufacturing innovation involves developing a new technique, concept, or tool. Long-term economic growth. Ahmed [8][5] analyzed the innovation performance of Australian businesses by combining innovation ability and stimulus into a unified framework. When compared to academic organizations, government agencies appear to play a greater role in integrating applied and basic research for scientific articles and patents covering alternative energy technologies, including solar, wind, and biofuels [9, 10]. According to research by [11], who analyzed the patent output of inventors with and without engineering degrees, those with a scientific background are more likely to develop novel technology combinations. Since innovation is both a source of competitive advantage for firms and a key factor in economic growth, it is important to understand the factors contributing to its creation and decline. For instance, innovation is now widely accepted as a critical factor in company success because of the productivity gains it brings about [11]. Researchers in the past have looked into a wide range of innovation-related variables. Some of the topics covered are as follows: corporate governance [12], institutional ownership [13], stock liquidity [14, 15]. The study of Dai, et al. [16] showed, for instance, that private enterprises dependent on external financing and with limited access to loans from local banks are more likely to innovate. Instead of being purchased by huge public organizations, they reasoned that tiny, innovative firms might take advantage of competition inside the banking industry to gain access to financing. Guan and Qamruzzaman [17], Shahzadi, et al. [18] found that companies that utilized innovative alliances were likelier to participate in patenting activities despite the weak patent application procedure. A patent is an intangible asset crucial to improving the efficiency with which innovations are implemented. Having a patent on your innovation means you have the sole right to profit from it and prevent others from copying it. There is much literature on the topic of innovation in low-quality institutional settings. Factors and characteristics of a weak institutional environment include uneven access to information in markets, a poorly trained labor force, obstacles to entering new markets, ineffective property and judicial protections, and a shaky rule of law. Structured and demanding institutions can accelerate fundamental and crucial improvements in process and product technology, which is why government laws and policies can stifle or foster innovation. On the other hand, creativity may be stifled in a setting with many bureaucratic hurdles to overcome. As a result of these obstructions, businesses must spend more money on things like compliance and less on research and development, on the other hand, that a well-functioning legal system inspires innovation. In addition, a 27% increase in innovation is linked to a 1 point rise in the Economic Freedom of the World Index (EFW) published by the Fraser Institute. The growth of innovation is stifled by weak institutions but fostered by strong ones. A corporation that operates in a jurisdiction where its patent application was not approved may nonetheless be able to innovate without patent enforcement due to the ambiguity of its intellectual property rights [19-21]. [22] argued that the value of patents declines in markets with low appropriability. In a nutshell, in an unpredictable institutional framework, both international and domestic enterprises perform similarly in terms of patent intensity. The institutions of a country are the codified frameworks and norms by which its citizens and other social actors interact with one another and the world around them. Institutions of regulation include the regulatory framework, the legal framework,

and the enforcement apparatus [23-25]. There are three angles from which previous researchers have looked at the institutions' function in the formulation of innovation. Secondly, a large body of literature has elucidated the moderating function of institutional elements as a framework to justify innovation at the company level. According to Sy, et al. [26] Hanif [27] observed that ownership of Chinese target enterprises by firms from developed economies has a detrimental effect on the acquired companies' innovation performance after the purchase.

The motivation of the study is rooted in the acknowledgment that nations with lower incomes frequently encounter substantial obstacles in promoting technological progress. Policymakers and stakeholders can gain valuable insights by comprehending the significance of institutional quality, trade, and education. The potential impact of the findings from this study lies in their ability to provide valuable insights that can guide the development of strategies and policies aimed at enhancing institutional quality, promoting trade, and improving education systems. Ultimately, these efforts have the potential to foster technological innovation and drive economic growth in nations with lower-income levels.

The study contributes significantly to the literature on the complex relationship between institutional quality, technological innovation, trade, and education in low-income countries. By examining the complex interplay among multiple variables, this research aims to shed light on the fundamental mechanisms through which institutional quality impacts the trajectory of technological innovation. This study highlights the importance of trade and education as intermediary variables in the examined correlation. It emphasizes their role in enhancing the capacity of economically disadvantaged countries to leverage institutional quality to advance technological progress. The current study expands our understanding of the various factors that impact technological innovation within these countries. Additionally, it provides valuable insights that can be utilized by policymakers and practitioners who are seeking to foster development that is propelled by innovation within similar contexts.

Furthermore, the significance of this study lies in its utilization of a comprehensive dataset and rigorous application of robust statistical methods to examine the hypothesized associations meticulously. By employing a robust sample size of lower-income nations and implementing rigorous measures to account for potential confounding variables, this study greatly enhances the dependability and relevance of its results. The results of this study suggest a significant and positive correlation between the quality of institutions and technological innovation across the nations under investigation. Moreover, the current study offers empirical evidence that underscores the substantial influence exerted by trade and education in mediating the association mentioned above. The results obtained from this study suggest that there is a positive relationship between trade openness and educational attainment, and their combined effect amplifies the influence of institutional quality on technological innovation. The findings mentioned above have important implications for policymakers. They highlight the urgent need to prioritize institutional reforms, promote trade integration, and allocate educational resources. These measures are crucial for facilitating technological progress in lower-income nations. The present study makes a significant and valuable contribution to the existing literature by deepening our understanding of the complex dynamics between institutional quality, trade, education, and technological innovation. The research findings presented in this study provide significant and noteworthy insights that hold relevance for both scholarly discourse and the formulation of efficacious policy strategies.

2. Literature survey and hypothesis development

2.1. Institutional quality-led technological innovation

Constant innovation is required to adjust to the ever-changing conditions of a capitalist system. Competition is fierce, markets are unpredictable, and technological advancements are lightning-fast in today's business world [28]. Innovation is essential to the long-term success of many human endeavors, including but not limited to education, industry, and economic growth. The term "innovation" itself was first used by Schumpeter Schumpeter [29][. He continued by saying that innovation means coming up with a new approach, concept, or tool in manufacturing. National innovation capacity is the most important factor in a country's long-term economic growth [30, 31]. The literature on innovation examines the idea of innovation from different angles and considers many factors. For example, we can define innovation as introducing novel product lines and creating novel production processes using and modifying existing inventions and resources. Prajogo and McDermott [32] examined the innovation effectiveness of Australian businesses using a framework that combines innovation capability and stimulus. Applied and basic research for scientific articles and patents relating to alternative energy technologies like solar, wind, and biofuels appears to be integrated more by government agencies than academic institutions. Morbey [7] looked at the R&D spending and influence of US corporations on firm performance from 1976 to 1985 and found that it was positively correlated with sales growth. Researchers Gruber and Harhoff [8] found that inventors with a scientific background are more likely to develop novel technology combinations by comparing the patent output of inventors with and without engineering degrees. Understanding the causes of innovation's birth and death is crucial, as it is a competitive advantage for

businesses and an engine of economic growth. For example, thanks to the productivity gains it brings about, innovation is now generally recognized as an important factor in the success of businesses. Many different aspects of innovation have been studied in the past. Some of the topics discussed are as follows: corporate governance institutional ownership, stock liquidity, labor laws, competition, bankruptcy, investors' attitudes toward failure, corporate venture capital, receiving inbound grants for entrepreneur investment, the role of competition at the bank level, firm boundaries, and analyst coverage. For example, Wu, et al. [33] found that private firms that cannot easily obtain loans from local banks and must instead rely on external financing are more likely to innovate. They reasoned that small, innovative businesses would be better off not being acquired by large public corporations and instead taking advantage of competition within the banking industry to secure financing even though the patent application process is cumbersome.

Hypothesis: institutional Quality (IQ) is positively associated with Technological Innovation (TI)

2.2. Trade openness led to technological innovation.

Existing literature suggests that trade openness and technological innovation have a positive relationship. Trade openness provides access to required factor inputs and imported technology, translating to economic growth. Innovation is the engine of development, and it can significantly improve employment. However, the relationship between technological innovation and economic growth is not linear, requiring a sound institutional framework, policies, and incentive systems. Achieving sustainable development within the institutional framework requires macro-policy adjustments, and flexible economic policies under the strategic stability goal will boost economic growth. Achieving sustainable development within the institutional framework requires macro-policy adjustments. Uncertain economic policies can worsen existing and future investment environments, threatening stable economic growth. However, flexible economic policies under the strategic stability goal will boost economic growth. China's policies have kept pace with the times and promoted rapid economic development. Bo, et al. [34] verified that the global financial crisis 2008 brought disaster to the world economy. However, China made timely policy adjustments in domestic and foreign situations. The policy ensured the primary stability of China's economy and accelerated the pace of economic recovery. In addition, the Belt and Road policy has strengthened infrastructure construction and connectivity among countries along the routes and strengthened China's strategic trade and economic position. The policy has driven the economic growth of countries along the routes.

The literature review on the nexus between trade openness and technological innovation suggests a positive relationship between trade openness and technological innovation [3, 5, 35-43]. Gong [44], Zhang, et al. [45] found that economic openness promotes economic growth and innovation. The study by [46] explored the dynamic relationships between technological innovation, trade openness, and GDP in Saudi Arabia and found that trade openness provides access to the required factor inputs and imported technology, which translates to economic growth. The study by Raspovic, et al. [47] investigated the nonlinear relationship between innovation, economic growth, and trade openness and CO_2 emissions and found that innovation and trade openness reduce CO_2 emissions. Trade openness impacts the economies' dynamics by affecting firms' motives for innovation. The channels through which trade openness policies affect innovation in countries are fundamentally foreign direct investment, imports, exports, and competition [35, 48, 49]. The literature review on the nexus between trade openness and technological innovation suggests a positive relationship. Trade openness provides access to required factor inputs and imported technology, translating to economic growth. The study of [47] found that innovation and trade openness reduce CO_2 emissions. The study by [50] found that trade openness impacts the economies' dynamics by affecting firms' motives for innovation. The channels through which trade openness policies affect innovation in countries are fundamentally foreign direct investment, imports, exports, and competition[51]. The study by [52] explored the dynamic relationships between technological innovation, trade openness, and GDP in Saudi Arabia and found that trade openness provides access to the required factor inputs and imported technology, which translates to economic growth. Innovation is the engine of development. R&D investment and innovation performance provide great potential for the economic development of enterprises and countries. Whether the technologies are imported or developed independently, enterprises can increase their competitiveness and market shares by applying patented technologies [23, 36, 53-55]. For countries, the economic effect of innovation requires the joint role of infrastructure, policies, and incentive systems. Innovation can significantly improve employment, and high-tech industries can absorb more jobs than low-tech industries. However, technological innovation and economic growth are only partially linear. There is an inverse u-shaped relationship between technological innovation and economic growth in the economic cycle, confirming that the economic growth rate rises when the economy introduces a quadratic term for innovation. Law et al. took Malaysia as the subject [13, 16, 56-61]. They denoted that the quality of technological innovation contributes to the growth of the national economy, and technological exchange is an important factor in promoting economic growth. Therefore, it is necessary to build a sound

institutional framework, accumulate the quality of human capital, build extensive network connections, and speed up the marketization process of scientific and technological innovation.

The study by Kassi, et al. [62] found a positive and statistically significant linkage between trade openness and technological innovation, advocating the fostering effects of domestic trade internationalization on technological innovation. The study by Marco-Lajara, et al. [63]highlighted three main channels through which international trade can affect innovation by domestic firms: increasing market size, intensifying market competition, and facilitating the transfer of technology. The channels through which trade openness policies affect innovation in countries are fundamentally foreign direct investment, imports, exports, and competition. The study by Chhabra et al. found that innovation and trade openness reduce CO_2 emissions. The study by [64] found that trade openness impacts the economies' dynamics by affecting firms' motives for innovation. The study by Abdulsalam and Tukur [65] demonstrated that digital technology has enhanced human capital and accelerated economic growth. However, the relationship between technological innovation and economic growth is not entirely linear. There is an inverse u-shaped relationship between technological innovation and economic growth in the economic cycle, which confirms that the economic growth rate rises when the economy introduces a quadratic term for innovation ([64]. Law et al. took Malaysia as the subject. They denoted that the quality of technological innovation contributes to the growth of the national economy, and technological exchange is an important factor in promoting economic growth [66, 67].

Hypothesis: Trade Openness (TO)) positively associated with Technological Innovation (TI)

2.3. Education led to technological innovation.

Technological innovation is crucial in driving economic progress and promoting social advancement. Throughout history, scholars have investigated the relationship between education and technological innovation. They have recognized the significant impact that education can have on fostering creativity. This literature review aims to offer a thorough analysis of prior research that clarifies the relationship between education and technological innovation.

Several scholarly investigations have consistently emphasized the positive correlation between education and technological innovation. A study by [68] found that education is pivotal in propelling technological advancement. The relationship between education and technological innovation has been a topic of inquiry and study in several academic fields. The extent to which formal and informal education fosters an environment conducive to technological advancements has been investigated by scholars. This literature review provides insights into how education influences and shapes technological innovation by synthesizing existing research. Numerous studies highlight the importance of education in facilitating the transmission of knowledge, which is a key driver of technological innovation. Formal education systems, such as universities and research institutions, serve as knowledge repositories where specialists in various disciplines conduct research and generate new insights. These insights are disseminated via academic publications, conferences, and collaborations, enriching the innovation landscape by laying the groundwork for future advances. In this sense, education facilitates the exchange of ideas that can inspire innovation, which can be attributed to its capacity to cultivate human capital and facilitate acquiring information and skills crucial for promoting innovation. Similarly, [69] presented empirical evidence that establishes a positive correlation between higher levels of education and improved production alongside advancements in technology. The importance of education in promoting technological innovation has been duly acknowledged. Based on a study conducted by [70, 71], a positive correlation exists between the level of educational achievement within a nation and its rates of technological innovation. The research highlights the importance of improving educational accessibility, particularly in developing countries, to foster innovation and drive economic progress.

The significance of education goes beyond mere accessibility, as the quality of education plays a crucial role in promoting technological innovation. [72, 73] conducted a study that unveiled a positive correlation between the quality of education, as measured by student achievement levels, and technological advancement. Countries prioritizing enhancing their education systems tend to experience higher levels of technological innovation. Research has demonstrated that education exerts a discernible impact on technological innovation across diverse sectors. The investigation conducted by [74] focused on the manufacturing industry and found a positive correlation between higher levels of education among workers and increased innovation efforts within organizations. The research highlighted the importance of education in fostering creativity within specific industries.

Education is crucial in supporting research and development (R&D) efforts, which are vital for promoting technological advancements. A study by [75] revealed a noteworthy correlation between education and investments in research and development (R&D). The findings suggest that countries with higher educational attainment allocate more resources to research and development (R&D), promoting increased technological innovation[76]. Education provides the skills and

competencies necessary for technological innovation. A well-rounded education allows individuals to think critically, solve problems, and think creatively. These characteristics are necessary for identifying problems, conceiving novel solutions, and adapting to swiftly changing technological landscapes[77, 78]. In addition, education fosters a mindset of lifelong learning, allowing innovators to remain abreast of the most recent developments and trends in their respective fields. Frequently, modern technological innovation flourishes at the intersection of various disciplines. Innovation thrives in an environment that fosters interdisciplinary learning and collaboration in the classroom. Diverse perspectives, methodologies, and knowledge bases result in innovative solutions that may not have been possible within the confines of a single discipline when individuals with diverse educational backgrounds collaborate. Consequently, education that promotes interdisciplinary engagement significantly contributes to the cross-pollination of ideas required for innovative innovations.

In addition to traditional educational institutions, entrepreneurship education is crucial in bringing technological innovation from concept to market [79, 80]. Entrepreneurial education equips individuals with the competencies to transform innovative concepts into practical applications and products. It cultivates an entrepreneurial mindset that values risk-taking, resiliency, and adaptability—crucial for navigating innovation challenges. In addition, this type of education accentuates the significance of market knowledge, allowing innovators to align their creations with actual market demands. Education shapes individual innovators and impacts the innovation ecosystem via policy and regulation. Educated individuals frequently hold critical positions in government and non-government organizations, where they shape policies that support research and innovation. These policies may include funding mechanisms, intellectual property regulations, and academic and industrial collaboration incentives. Thus, education indirectly contributes to the growth of an environment conducive to technological innovation [81-83].

Existing research emphasizes education's important and multifaceted role in fostering technological innovation. Education influences innovation on multiple levels, from knowledge transfer and skill development to fostering interdisciplinary collaboration and an entrepreneurial mindset. Understanding the dynamic interplay between education and technological innovation is crucial for policymakers, educators, and researchers who seek to foster environments that foster continuous advancements in various disciplines. Nevertheless, it is essential to recognize that the relationship between education and innovation is complex and influenced by various contextual factors, necessitating additional research and investigation[34, 84].

Hypothesis: Education positively contributed towards Technological Innovation (TI)

3. Data and methodology of the study

3.1. Model specification

The motivation of the study is to assess the impact of institutional quality, trade openness and education on technological innovation in SSA nations for the period 2005-2020.

$$RI \int EDU, TR, EDU \quad (1)$$

We can construct a multiple linear regression model to transform the given variables (TI, IQ, TR, and EDU) into a regression equation. Let us assume that these variables influence technological innovation (TI). The regression equation can be written as:

$$TI = \beta 0 + \beta 1 \times IQ + \beta 2 \times TR + \beta 3 \times EDU + \varepsilon \quad (2)$$

Where $\beta 0$ is the intercept term, representing the baseline level of technological innovation when all predictor variables are zero. $\beta 1, \beta 2$, and $\beta 3$ are the coefficients associated with IQ, TR, and EDU, respectively. They indicate the change in technological innovation for a one-unit change in each respective predictor variable, holding other variables constant. ε represents the error term, capturing unobserved factors that affect technological innovation but are not included in the model.

Higher institutional quality (IQ) can contribute to an environment that fosters innovation. Effective institutions provide clear property rights, enforce contracts, and ensure the rule of law, reducing business uncertainty and encouraging investment in research and development. Thus, a positive coefficient (β1>0) for IQ suggests that better institutional quality is associated with increased technological innovation. Trade openness can expose countries to new technologies, ideas, and markets. Increased international trade can lead to the transfer of knowledge, technology, and best practices

across borders. A positive coefficient (β2>0) for TR indicates that higher trade openness is associated with greater technological innovation due to the spillover of ideas and the potential for learning from trading partners.

Education plays a crucial role in nurturing a skilled and innovative workforce. Higher levels of education contribute to a population's ability to understand, adapt, and develop new technologies. A positive coefficient (β2>0) for EDU suggests that increased education levels are linked to higher technological innovation as educated individuals contribute to research, development, and creative problem-solving.

The empirical equation to be assessed through several panel data estimation techniques such as the cross-sectional dependency test, the slope of homogeneity, second generation panel unit root test [85], the panel cointegration test following [86-88], and the coefficients of IQ, TR, and EDU to be extracted by executing the dynamic seemingly correlated estimation.

The Cross-sectional Dependency test, also known as the CD-Pesaran test, is a statistical technique employed to assess the presence of cross-sectional dependence among individual units within panel data. It addresses the possibility that observations across different entities (such as countries, firms, or regions) are not entirely independent, potentially leading to biased statistical inferences.

Equation:

The CD-Pesaran test involves estimating the following equation:

$$yit = \alpha i + \beta xit + \epsilon ityyit = \alpha i + \beta xit + \epsilon it$$

The second-generation panel unit root tests are statistical tools to gauge whether a panel dataset demonstrates a unit root. This term refers to instances where a time series variable exhibits a stochastic trend, indicating that it does not settle at a fixed level over time. Such unit roots can lead to misleading regression outcomes and impact statistical conclusions' reliability. A well-known example in this category is the Common Augmented Dickey-Fuller (CADF) test, an extension of the Augmented Dickey-Fuller (ADF) test commonly employed for assessing unit roots in individual time series. The CADF test accommodates variations in cross-sectional dependency and heterogeneity within panel data. It amalgamates the individual ADF test results into a single panel test statistic, which is then compared against predefined critical values to ascertain the existence of a unit root.

The formulation for the CADF test can be represented as follows:

$$\Delta yt \ = \ \alpha \ + \ \beta t \ + \ \gamma yt - 1 \ + \ \delta 1 \Delta yt - 1 \ + \ \ldots \ + \ \delta p \Delta yt - p \ + \ \varepsilon t$$

The Cross-sectional Implied PPP (CIPS) test draws inspiration from the Purchasing Power Parity (PPP) concept. This principle posits that exchange rates between countries should mirror relative price levels. The CIPS test scrutinizes the validity of PPP across a panel of countries.

The equation for the CIPS test takes the form:

$$ln(et) \ = \ \alpha \ + \ \beta t \ + \ \gamma ln(et - 1) \ + \ \delta 1 \Delta ln(et - 1) + \ldots + \delta p \Delta ln(et - p) \ + \ \varepsilon t$$

The CADF and CIPS tests involve estimating model parameters and conducting hypothesis tests to assess whether coefficients related to lagged variables significantly deviate from zero. Should the test statistic surpass the critical value, it suggests the presence of a unit root, indicating the non-stationary nature of the variable. Conversely, suppose the test statistic falls below the critical value. In that case, it indicates the absence of a unit root, signifying that the variable is stationary.

The concept of Dynamic Seemingly Unrelated (DSUR) models is a widely used statistical framework that allows for the analysis of multiple time series data sets that are potentially interrelated. The Cointegrating Regression (DSUR) is a statistical technique employed for estimating equations that exhibit cointegration. Cointegration pertains to the enduring association between non-stationary variables, denoting their possession of a unit root. The DSUR methodology facilitates estimating this relationship by considering the dynamic nature of the variables involved.

In the context of DSUR, it is important to note that each equation within the system is estimated individually using the Ordinary Least Squares (OLS) method. However, it is assumed that the error terms from each equation are correlated,

and this correlation is duly considered during the estimation process. This approach enables more efficient parameter estimates than estimating each equation individually.

The DSUCR model can be represented as follows:

$$\Delta Yit = \alpha i + \beta iZit + \sum j = 1p\phi ij\Delta Yi, t - j + \sum k = 1q\theta ik\Delta Zi, t - k + \varepsilon it\Delta Yit = \alpha i + \beta iZit + \sum j = 1p\phi ij\Delta Yi, t - j + \sum k = 1q\theta ik\Delta Zi, t - k + \varepsilon it$$

In this equation: ΔY_{it} Is the first difference of the dependent variable for time series ii at time tt. ααiαirepresents the intercept specific to time series ii. β_{i} signifies the coefficient associated with the cointegrating relationship variable Z_{it} For time series ii. Z_{it} denotes the cointegrating variable for time series ii at time tt. ϕijϕij represents the coefficients of the lagged first differences of the dependent variable $Yi_{,\mathrm{t-j}}$ corresponds to the lagged first difference of the dependent variable for time series ii at time t–j. θik signifies the coefficients of the lagged first differences of the cointegrating variable. ΔZi,t−k represents the lagged first difference of the cointegrating variable for time series ii at time t−k. εitεit denotes the error term for time series ii at time t.

The cointegrating relationship is expressed through the coefficients γ, which signify the enduring association between the variables in the long run. The inclusion of lagged dependent variables in Z_t effectively captures the dynamic characteristics inherent in the system.

Several methods are available to estimate the DSUR model, including the Fully Modified OLS (FMOLS) and the Dynamic OLS (DOLS) approach. These methods effectively tackle the potential problems of endogeneity and serial correlation that may arise during the estimation process[89].

In general, the DSUR technique is valuable for analyzing the enduring association between variables within a dynamic system and considering the correlation among the error terms. This particular methodology finds frequent application within econometrics and time series analysis.

4. Interpretation and Discussion

Table 1 displayed the slope of homogeneity and cross-sectional dependency results and revealed the presence of heterogeneity properties and cross-sectional dependency among the research units.

Table 1 Results of Slop of homogeneity and CDS test

	LM_{BP}	LM_{PS}	LM_{adj}	CD_{PS}	Δ	Adj.Δ
POV	331.031***	45.43***	240.426***	28.059***	24.008***	132.85***
FII	284.349***	15.291***	109.639***	39.077***	74.574***	72.383***
REC	250.773***	36.683***	167.05***	42.477***	56.217***	117.779***
EQ	373.826***	42.327***	211.562***	33.847***	20.882***	147.697***
FDI	427.935***	41.342***	200.084***	35.339***	19.618***	118.275***

Following the CDS test results, the study performed the second generation unit root test commonly known as CIPS and CADF. Table 2 exhibited the results of panel unit root tests. The test statistics show that the variables become stationary after the first difference operation, I(1).

Table 2 Results of Second generation Panel unit root test

Variables	**CADF test statistic**		**CIPS test statistic**		**CADF test statistic**		**CIPS test statistic**	
	for constant		**for constant**		**for constant & and trend**		**for constant & and trend**	
	Level	**first difference**	**Level**	**first difference**	**level**	**first difference**	**level**	**first difference**
EF	-1.658	-5.246***	-1.301	-7.47***	-2.071	-5.187***	-2.705	-4.09***

FD	-1.542	-3.528***	-1.45	-4.601***	-1.533	-2.646***	-1.753	-5.328***
EG	-1.328	-2.566***	-1.181	-2.433***	-2.112	-2.576***	-1.837	-4.382***
NRE	-1.028	-5.133***	-2.127	-5.27***	-2.442	-3.783***	-1.279	-2.185***
TO	-2.7	-3.291***	-2.933	-7.504***	-1.366	-7.131***	-1.431	-5.15***

The study implemented a panel cointegration test following Pedroni [88], Kao [90] and Westerlund [86]; the results of the panel cointegration test are displayed in Table 3. Test statistics show a long-run association between institutional quality, education, trade openness and technological innovation.

Table 3 Results of Panel cointegrating test

Model	**FDI--->EC**	**FDI--->GG**	**FDI--->ED**	**FDI--->ER**
Gt	-15.092***	-12.3***	-14.024***	-11.365***
Ga	-11.746***	-12.418***	-14.929***	-14.376***
Pt	-12.067***	-9.414***	-13.821***	-6.491***
Pa	-10.813***	-10.131***	-13.268***	-12.291***
KRCPT				
MDF	8.698***	-3.297***	17.789***	2.44***
DF	-9.371***	-10.942***	14.546***	17.583***
ADF	17.586***	5.362***	-4.968***	-9.988***
UMDF	8.086***	-0.59***	9.028***	-0.986***
UDF	14.745***	-1.609***	11.022***	1.245***
PCT				
MDF	-3.767***	-9.849***	14.416***	-7.9***
PP	-3.767***	-9.849***	14.416***	-7.9***
ADF	15.966***	9.906***	14.664***	-1.019***

Following, the study implemented the dynamic SUR in exporting the coefficients of IQ, EDU, and TR on technological innovation in LIC. The results of DSUR estimation are displayed in Table 4.

Table 4 Results of DSUR estimation

	Coefficient	**Std. Error**	**t-Statistic**
IQ	0.14358	0.0438	3.278
TR	0.15755	0.0246	6.4044
EDU	0.13404	0.0293	4.5747
FD	0.14279	0.0243	5.8761
FDI	0.11913	0.016	7.4456
C	0.15564	0.0172	9.0488
	13.836	0.24013	57.6187
R2			
Adj R^2	0.9101		

The finding that the coefficient for institutional quality (IQ) demonstrates a positive and statistically significant impact on technological innovation (β_{IQ}=0.14358; p<0.001). It can be inferred that countries with higher levels of institutional quality create a conducive environment for technological advancements and effective policy suggestions. Our study is supported by the exiting literature such as [6, 36, 39, 91]. Institutional quality encompasses the robustness and effectiveness of a nation's institutions, encompassing its legal framework, regulatory environment, governance structures, and policies. When these institutions function effectively, they can cultivate an environment that promotes innovation and entrepreneurship [2].

One of the reasons behind the positive correlation observed between intelligence and technical innovation is the presence of superior institutions in nations, which increases the likelihood of having clear and well-enforced property rights [2, 92, 93]. This gives individuals and organizations the assurance to participate in research and development, understanding that the benefits of their findings will be actualized. Moreover, robust institutions can foster knowledge transfer, facilitate cooperation, and protect intellectual property rights [94, 95]. These factors play a pivotal role in driving technological advancements and growth. Moreover, countries with superior institutional quality frequently exhibit greater political and economic stability, which is exhibited by the current situation and has the potential to attract foreign direct investment while simultaneously fostering a climate that encourages domestic enterprises to actively participate in research and development activities [23, 96, 97]. Moreover, proficient institutions can offer policy recommendations and assist with initiatives that promote innovation, including research funding, tax incentives, and streamlined regulatory processes. Nevertheless, it is imperative to acknowledge the substantial constraints and alternative explanations that must be considered concerning this finding. Although there is a statistically significant positive correlation between IQ and technical innovation, it is important to note that this does not imply a causal relationship. Human capital, infrastructure, and market conditions can influence technical innovation.

Moreover, it is imperative to thoroughly examine the precise metrics utilized for evaluating institutional quality and technical innovation[98, 99]. Various studies may employ different indicators, and the choice of indicators can influence the results. Moreover, it is important to note that the outcomes may vary across different countries and regions because institutions' quality and impact on innovation are contingent upon specific contextual factors. The recent discovery that institutional quality has a positive and statistically significant impact on technological innovation suggests that nations with stronger institutions are more likely to provide a conducive environment and policy recommendations that promote innovation [100, 101].

Regarding trade openness effects on technological innovation, the study revealed a positive and statistically significant linkage between trade openness and technological innovation (β_{TR}=0.15755; p<0.001)., advocating the fostering effects of domestic trade internationalization on technological innovation [102, 103]. The study of [104, 105] revealed a positive and statistically significant linkage between trade openness and technological innovation, advocating the fostering effects of domestic trade internationalization on technological innovation. The channels through which trade openness policies affect innovation in countries are fundamentally foreign direct investment, imports, exports, and competition[106]. The study by [107] explored the dynamic relationships between technological innovation, trade openness, and GDP in Saudi Arabia and found that trade openness provides access to the required factor inputs and imported technology, which translates to economic growth. The study by [108, 109]et al. investigated the nonlinear relationship between innovation, economic growth, and trade openness and CO_2 emissions and found that innovation and trade openness reduce CO_2 emissions. International trade can affect innovation by domestic firms through increasing market size, intensifying market competition, and facilitating the diffusion of knowledge and technology. The study by Salam Abubakar, et al. [110] demonstrated that digital technology has enhanced human capital and accelerated economic growth. However, technological innovation and economic growth are only partially linear. There is an inverse u-shaped relationship between technological innovation and economic growth in the economic cycle, confirming that the economic growth rate rises when the economy introduces a quadratic term for innovation [6]. To achieve sustainable development within the institutional framework, macro-policy adjustments are necessary. Uncertain economic policies can worsen existing and future investment environments, seriously threatening stable economic growth [25, 111, 112]. However, flexible economic policies under the strategic stability goal will boost economic growth. China's policies have kept pace with the times and promoted rapid economic development. The Belt and Road policy has strengthened infrastructure construction and connectivity among countries along the routes and strengthened China's strategic trade and economic position. The policy has driven the economic growth of countries along the routes. Trade openness provides access to required factor inputs and imported technology, translating to economic growth. Innovation is the engine of development, and R&D investment and innovation performance provide great potential for the economic development of enterprises and countries. To achieve sustainable development within the institutional framework, macro-policy adjustments are necessary.

The finding that education (β_{EDU}=0. 13404; p<0.001) positively influences technological innovation in low-income countries (LICs) and aligns with prior research [113-116]. It enhances our comprehension of the connection between education and innovation. Multiple studies have consistently demonstrated that education positively impacts the advancement of technical innovation. Education equips individuals with the necessary knowledge, competencies, and aptitudes to actively engage in creative endeavors. Individuals who acquire technical expertise are more aptly equipped to conceive and implement novel technologies, leading to significant advancements in economics and technology. Access to education plays a crucial role in fostering technical innovation in low-income countries (LICs). When education is made accessible to a larger population segment, the potential pool of innovators expands. A larger population of educated individuals can significantly enhance the generation and dissemination of novel concepts, fostering innovation across diverse domains. Moreover, education has the potential to foster an innovative culture through the promotion of critical thinking, problem-solving skills, and creativity. The possession of these characteristics is essential for the identification and resolution of technical challenges, as well as the development of innovative solutions. Education also enhances adaptability and learning, which are crucial in a constantly evolving technological landscape.

A positive and statistically significant correlation between education and technological innovation suggests that allocating resources toward education could yield long-term benefits for low-income countries [38, 41, 58, 66, 117-121]. By prioritizing education and ensuring universal access, these nations have the potential to cultivate a skilled workforce capable of propelling technological progress and fostering economic growth. However, it is important to acknowledge the potential limitations and complexities arising from the interaction between education and technological progress. The quality of education is a significant matter to take into consideration [122]. If the quality of education is subpar, simply increasing its accessibility may not be sufficient. To ensure that individuals acquire the necessary skills and knowledge for innovation, it is imperative to focus on enhancing the relevance and effectiveness of educational institutions [123, 124]. Infrastructure, research and development capacity, and supporting policies are crucial in fostering technological innovation. Education may not directly impact innovation outcomes [125-128]. It is important to comprehend the broader ecosystem and the intricate interplay of multiple elements contributing to technological innovation in low-income countries (LICs). The finding that education has a positive and statistically significant impact on technological innovation in low-income countries (LICs) aligns with prior research [129, 130]. Access to education facilitates the rapid acquisition of technical knowledge. It fosters the cultivation of an innovative culture, thereby enabling individuals to make valuable contributions to the advancement of technology. However, it is imperative to consider the quality of education and other contextual variables that influence the relationship between education and technological innovation in low-income countries [131-134].

5. Conclusion

The research findings indicate a correlation between elevated levels of institutional quality, establishing a favorable setting for technological progress, and developing sound policy recommendations. The current study is supported by a substantial body of existing literature emphasizing institutions' crucial role in promoting and enabling innovation and entrepreneurship. Moreover, the results of this research study provide compelling evidence of a substantial and favorable association between trade openness and technological innovation. The statement above underscores the significant contribution of both domestic and international trade in fostering and cultivating innovation within an economy. Moreover, this research endeavors to shed light on the positive influence of education on technological advancement, emphasizing the paramount importance of ensuring widespread and superior educational opportunities. However, it is crucial to consider alternative explanations and contextual factors that may influence the relationship between these variables. The current research acknowledges the need to examine the metrics utilized to evaluate institutional quality and technological innovation. It also takes into account the possible discrepancies that could exist among different countries and regions.

Furthermore, the results obtained from this research study have substantial implications for policymakers and practitioners involved in the operations of countries characterized by lower-income levels. The empirical evidence reveals a strong and statistically significant correlation between the quality of institutions and the level of technological innovation. The statement above highlights the significance of prioritizing endeavors to improve and strengthen institutional frameworks. The desired outcome can be achieved by implementing comprehensive reforms that strengthen the current legal framework, regulatory environment, governance structures, and policies. Creating a favorable institutional framework has considerable implications for countries in terms of their ability to successfully attract foreign direct investment, promote the active engagement of domestic enterprises in research and development activities, and foster an environment characterized by economic and political stability.

The research study further emphasizes the importance of trade openness in promoting technological innovation. It is of utmost importance for policymakers to prioritize policies that promote trade integration, encompassing both domestic

and international spheres. The desired outcome can be achieved by implementing various measures to promote international trade. These measures include the removal of barriers and restrictions that hinder the flow of goods and services across borders, simplifying and optimizing processes involved in conducting cross-border transactions and promoting and supporting industries that prioritize the exportation of goods and services. The expansion of market size, intensification of competition, and promotion of knowledge and technology diffusion are critical elements by which trade openness can significantly contribute to technological progress in countries with lower income levels. Moreover, the study highlights the importance of education in fostering and advancing technological innovation. It is of utmost importance for policymakers to allocate significant emphasis on investments in education, placing particular attention on ensuring universal access and augmenting the overall quality of educational provisions. Education can enhance an individual's ability to engage in creative endeavors and contribute meaningfully to technological progress by imparting crucial knowledge, skills, and competencies.

Furthermore, it is important to highlight that education is crucial in cultivating an environment conducive to promoting and developing innovation. The objective above is accomplished by fostering the development of critical thinking skills, enhancing problem-solving capabilities, and nurturing creativity. These competencies are essential for proficiently recognizing and resolving intricate technical challenges.

However, it is crucial to acknowledge the inherent limitations and complexities intertwined within the intricate relationship between education and technological innovation. The potential insufficiency of solely expanding the accessibility of educational opportunities becomes apparent when considering the possibility of substandard educational standards being offered. Therefore, engaging in efforts focused on enhancing educational institutions' relevance and effectiveness is crucial, emphasizing strengthening infrastructure, research and development capacities, and facilitating policy implementation. Moreover, policymakers must consider the intricate dynamics of the wider ecosystem and the interplay between various factors that contribute to the progress of technological innovation in nations characterized by lower income levels. The findings of this study underscore the crucial significance of institutional quality, trade openness, and education in fostering innovation-led development. The findings of this study have significant implications for policymakers and practitioners in various fields. These implications can be utilized to effectively design and execute strategies and policies that promote institutional reforms, facilitate trade integration, and encourage educational investments. The implementation of these measures has the potential to effectively stimulate technological advancements and facilitate economic growth in lower-income countries.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

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