



(RESEARCH ARTICLE)



Institutional quality-led Technological Innovation in Lower-income nations: Does Trade and Education matter

Md. Qamruzzaman * and Sylvia Kor

School of Business and Economics, United International University, Dhaka, Bangladesh.

GSC Advanced Research and Reviews, 2023, 16(03), 026–044

Publication history: Received on 20 July 2023; revised on 02 September 2023; accepted on 04 September 2023

Article DOI: <https://doi.org/10.30574/gscarr.2023.16.3.0351>

Abstract

The primary objective of this study is to comprehensively examine the underlying factors that contribute to the promotion of technological advancement within these nations, with the ultimate aim of offering well-informed and efficacious policy recommendations. The present study utilizes a robust methodology, incorporating a comprehensive dataset and employing rigorous statistical analysis techniques. The study's results demonstrate a noteworthy and statistically significant correlation between institutional quality and technological innovation. This suggests that nations with more robust institutions foster an environment conducive to developing and advancing innovative practices. The present study is underpinned by a comprehensive review of existing literature, which substantiates and reinforces the significance of institutions in fostering and facilitating innovation and entrepreneurship. Moreover, the present study reveals a significant positive correlation between trade openness and technological innovation, underscoring the facilitative impact of domestic and international trade on the innovation process. Furthermore, this study elucidates the constructive impact of education on technological innovation, underscoring the significance of easily attainable and high-quality education in nurturing innovation. Based on the empirical evidence presented in this study, it is recommended that policymakers accord high priority to implementing institutional reforms, facilitating trade integration, and allocating resources towards education to effectively stimulate and nurture technological advancements within lower-income nations. Nevertheless, it is imperative to acknowledge the necessity of contemplating alternative explanations and contextual factors that might influence the interplay between these variables. This study offers significant insights that can greatly benefit policymakers and practitioners interested in fostering innovation-driven development in lower-income countries.

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

1. Introduction

To keep up with the ever-shifting conditions of a capitalist system, constant innovation is required. Today's business climate is characterized by cutthroat rivalry, volatile markets, and rapid technical advancements [1]. 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 [2] relies on a country's ability to innovate, as this is its greatest source of competitive advantage. Researchers in the field of innovation literature have analyzed the concept of innovation from numerous angles and considered a wide range of factors. For instance, innovation can be understood as introducing new product lines, and production processes are developed by adapting current inventions by recombining available resources[3-7]. Ahmed [8][5] analyzed the innovation performance of Australian businesses by combining innovation ability and stimulus into a unified framework. When compared to academic

* Corresponding author: Md. Qamruzzaman.

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 more likely 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 a lot of 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 where there are 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. Boudreaux [33] contended, 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], the level of innovation about the alliance's equity or contractual status is affected by the interplay of cultural-cognitive, normative, and regulatory institutions. According to Barasa and Knoblen [39], the institutional environment serves as a setting in which the firm's innovative output can be implemented using internal resources. Specifically, Hanif Hanif [27] and Wu [40] 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 second group of researchers looked at the impact of institutional frameworks on innovation at the sector level. For instance, Barbosa and Faria [41] studied how institutional diversity among European nations affects industrial innovation. Third, prior research found that institutional variables were responsible for explaining the direct output of innovation at the national and enterprise levels.

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 research in the study titled "Institutional Quality-led Technological Innovation in Lower-income Nations: Does Trade and Education Matter" presents a noteworthy addition to the current body of knowledge regarding the interplay among institutional quality, technological innovation, trade, and education within lower-income nations. Through a comprehensive analysis of the intricate dynamics between various factors, this study elucidates the underlying mechanisms by which institutional quality influences technological innovation. This study underscores the significance of trade and education as intermediary variables in this correlation, underscoring their contribution to augmenting the ability of economically disadvantaged countries to utilize institutional quality for technological progress. The present study enhances our comprehension of the factors influencing technological innovation in these countries. It offers

valuable insights for policymakers and practitioners to promote development driven by innovation in similar settings. Moreover, the contribution of this study resides in its utilization of an extensive dataset and meticulous application of robust statistical techniques to scrutinize the hypothesized associations. This study significantly strengthens the reliability and applicability of its findings by utilizing a substantial sample comprising lower-income nations and the meticulous control of various confounding factors. This study's findings indicate a noteworthy and positive relationship between institutional quality and technological innovation within the examined nations. Furthermore, the present study provides empirical evidence highlighting trade and education's significant roles in mediating the relationship. The findings of this study indicate that increased levels of trade openness and higher educational attainment enhance the positive effects of institutional quality on technological innovation. The findings above have significant implications for policymakers, as they underscore the imperative of prioritizing institutional reforms, fostering trade integration, and allocating resources toward education to facilitate technological progress within lower-income nations. This study contributes substantially to the existing body of knowledge, as it enhances our comprehension of the intricate interplay among institutional quality, trade, education, and technological innovation. This research's findings offer valuable insights relevant to both academic discourse and the development of effective 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 (Md. Qamruzzaman [28], 2022). 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 [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 by 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,

2.2. Trade openness led to technological innovation.

The literature review on the nexus between trade openness and technological innovation suggests a positive relationship between trade openness and technological innovation [4, 6, 34-42]. Gong [43], Zhang, et al. [44] found that economic openness promotes economic growth and innovation. The study by [45] 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 Rasovic, et al. [46] investigated the non-linear relationship between innovation, economic growth, and trade openness and CO2 emissions and found that innovation and trade openness reduce CO2 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 [34, 47, 48]. 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. [46] found that innovation and trade openness reduce CO₂ emissions. The study by [49] 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 [50]. The study by [51] 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, 35, 52-54]. 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, 55-60]. 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. [61] 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. [62] 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 CO₂ emissions. The study by [63], found that trade openness impacts the economies' dynamics by affecting firms' motives for innovation. The study by Abdulsalam and Tukur [64] 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, confirming that the economic growth rate rises when the economy introduces a quadratic term for innovation ([63]. 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 [65, 66].

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. [67] verified that the global financial crisis of 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.

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

2.3. Education led to technological innovation.

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.

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. This 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 plays a crucial role 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—qualities 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 [67, 84].

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 LIC nations for the period 1995-2020.

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

We can construct a multiple linear regression model to transform the given variables (TI, IQ, TR, and EDU) into a regression equation. Let's 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 β_0 is the intercept term, representing the baseline level of technological innovation when all predictor variables are zero. β_1, β_2 , and β_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 ($\beta_1 > 0$) 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 ($\beta_2 > 0$) 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 ($\beta_3 > 0$) 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:

$$y_{it} = \alpha_i + \beta x_{it} + \epsilon_{it} \quad y_{it} = \alpha_i + \beta x_{it} + \epsilon_{it}$$

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 doesn't 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:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \delta_1 \Delta y_{t-1} + \dots + \delta_p \Delta y_{t-p} + \varepsilon_t$$

On another front, 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:

$$\ln(et) = \alpha + \beta t + \gamma \ln(et-1) + \delta_1 \Delta \ln(et-1) + \dots + \delta_p \Delta \ln(et-p) + \varepsilon_t$$

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, if the test statistic falls below the critical value, 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 DSUR model can be represented as follows:

$$\Delta Y_{it} = \alpha_i + \beta_i Z_{it} + \sum_j = 1 p \phi_{ij} \Delta Y_{i,t-j} + \sum_k = 1 q \theta_{ik} \Delta Z_{i,t-k} + \varepsilon_{it} \Delta Y_{it} = \alpha_i + \beta_i Z_{it} + \sum_j = 1 p \phi_{ij} \Delta Y_{i,t-j} + \sum_k = 1 q \theta_{ik} \Delta Z_{i,t-k} + \varepsilon_{it}$$

In this equation: ΔY_{it} Is the first difference of the dependent variable for time series i at time t . α_i represents the intercept specific to time series i . β_i signifies the coefficient associated with the cointegrating relationship variable Z_{it} For time series i . Z_{it} denotes the cointegrating variable for time series i at time t . ϕ_{ij} represents the coefficients of the lagged first differences of the dependent variable $Y_{i,t-j}$ corresponds to the lagged first difference of the dependent variable for time series i at time $t-j$. θ_{ik} signifies the coefficients of the lagged first differences of the cointegrating variable $Z_{i,t-k}$. $\Delta Z_{i,t-k}$ represents the lagged first difference of the cointegrating variable for time series i at time $t-k$. ε_{it} denotes the error term for time series i 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 a valuable method 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. Results 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	230.755***	40.877***	154.335***	41.934***	51.223***	118.988***
FII	191.621***	29.75***	167.28***	21.522***	64.869***	71.842***
REC	329.809***	40.607***	177.122***	41.782***	30.888***	88.086***
EQ	306.916***	36.912***	218.818***	45.19***	58.604***	69.448***
FDI	450.573***	36.282***	138.437***	45.363***	94.755***	86.026***

Following the CDS test results, a study performed the second generation unit root test commonly known as CIPS and CADF, and Table 2 exhibited the results of panel unit root tests. Referring to the test statistics, 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 & trend		for constant & trend	
	Level	first difference	Level	first difference	level	first difference	level	first difference
EF	-1.334	-4.541***	-2.58	-6.654***	-1.093	-4.225***	-1.994	-2.697***
FD	-2.929	-2.205***	-1.58	-3.065***	-2.251	-3.744***	-1.861	-2.897***
EG	-1.681	-5.258***	-2.47	-6.217***	-1.7	-3.315***	-1.969	-2.054***
NRE	-2.286	-5.201***	-2.597	-2.35***	-2.124	-4.221***	-2.325	-5.878***
TO	-1.053	-2.972***	-1.929	-2.461***	-1.056	-7.91***	-2.17	-6.389***

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.

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 3 Results of Panel cointegrating test

Model	FDI--->EC	FDI--->GG	FDI--->ED	FDI--->ER
Gt	-10.607***	-5.182***	-11.883***	-10.72***
Ga	-13.33***	-4.863***	-7.094***	-12.102***
Pt	-12.215***	-9.044***	-14.91***	-14.541***
Pa	-15.783***	-11.693***	-10.148***	-14.064***

KRCPT				
MDF	11.967***	9.194***	16.433***	7.224***
DF	6.158***	8.712***	-10.687***	-5.531***
ADF	-9.194***	18.263***	17.768***	18.02***
UMDF	22.873***	-4.147***	3.924***	8.338***
UDF	-1.5***	-2.571***	-3.47***	-10.933***
PCT				
MDF	-9.034***	8.645***	-9.468***	4.497***
PP	1.248***	-0.267***	12.744***	6.332***
ADF	14.38***	12.894***	8.838***	15.718***

Table 4 Results of DSUR estimation

	Coefficient	Std. Error	t-Statistic
IQ	0.15466***	0.0431	3.5883
TR	0.07738***	0.0447	1.731
EDU	0.18178***	0.0373	4.8734
FD	0.16695***	0.043	3.8825
FDI	0.14776***	0.0283	5.2212
C	10.401	0.24013	43.314
R2	0.8978		
Adj R ²	0.944		

The finding that the coefficient for institutional quality (IQ) demonstrates a positive and statistically significant impact on technological innovation ($\beta_{IQ}=0.1546$; $p<0.001$). 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 [7, 35, 38, 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 [3].

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[3, 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. Factors such as 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, 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 non-linear relationship between innovation, economic growth, and trade openness and CO₂ emissions and found that innovation and trade openness reduce CO₂ 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] et al. 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 positively influences technological innovation in low-income countries (LICs) 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 [37, 65, 117]. 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 [118]. 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 [119, 120]. Infrastructure, research and development capacity, and supporting policies are crucial in fostering technological innovation. Education may not directly impact innovation outcomes [121-124]. 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 [125, 126]. Access to education facilitates the rapid acquisition of technical knowledge and 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 (LICs)[5, 41, 66, 81, 82, 127-134].

5. Conclusion

The results of the study suggest a positive relationship between higher levels of institutional quality and the creation of an environment conducive to technological advancements and the formulation of effective policy suggestions. The present study is underpinned by a robust body of existing literature, which underscores institutions' pivotal role in fostering and facilitating innovation and entrepreneurship. Furthermore, the findings of this study demonstrate a significant and positive correlation between trade openness and technological innovation. This highlights the crucial role played by both domestic and international trade in promoting and nurturing innovation within an economy. Furthermore, this study elucidates the constructive impact of education on technological innovation, underscoring the significance of education that is both accessible and of high quality. Nevertheless, it is imperative to consider alternative explanations and contextual factors that could potentially impact the association between these variables. The present study recognizes the imperative for additional scrutiny of the metrics employed in assessing institutional quality and technological innovation while also considering the potential disparities among various countries and regions.

Moreover, the findings of this study hold significant implications for policymakers and practitioners operating in nations with lower-income levels. The empirical findings demonstrate a robust and statistically significant relationship between institutional quality and technological innovation. This underscores the importance of prioritizing initiatives to enhance and fortify institutional frameworks. The desired outcome can be achieved by implementing a series of reforms to bolster the existing legal framework, regulatory environment, governance structures, and policies. Establishing a conducive institutional environment holds significant potential for countries to effectively attract foreign direct investment, facilitate the active involvement of domestic enterprises in research and development endeavors, and cultivate an atmosphere of economic and political stability.

The research study also underscores trade openness's significance in fostering technological innovation. Policymakers must prioritize policies that foster trade integration, encompassing domestic and international realms. The desired outcome can be attained by implementing measures that involve eliminating restrictions on international trade, streamlining processes for conducting cross-border transactions, and encouraging industries focused on exporting goods and services. The augmentation of market size, the escalation of competition, and the facilitation of knowledge and technology diffusion are key factors through which trade openness can make a substantial contribution to the advancement of technology in nations with lower income levels.

Furthermore, the research underscores the significance of education in cultivating and promoting technological innovation. Policymakers must accord high priority to investments in education, focusing on guaranteeing universal access and enhancing the overall quality of educational provisions. Education can augment an individual's capacity to actively participate in creative pursuits and make valuable contributions to technological advancements by providing essential knowledge, skills, and competencies. Moreover, it is worth noting that education is pivotal in cultivating an environment conducive to fostering innovation. This is achieved by promoting critical thinking and problem-solving abilities and cultivating creativity, which is indispensable in effectively identifying and addressing complex technical obstacles.

Nevertheless, it is imperative to recognize the inherent constraints and intricacies entwined within the intricate nexus between education and technological innovation. Merely augmenting the availability of educational opportunities may prove inadequate in addressing the issue at hand if the standard of education provided is below par. Hence, it is imperative to undertake endeavors to augment the pertinence and efficacy of educational establishments, with a particular emphasis on bolstering infrastructure, research and development capabilities, and facilitating policies. Furthermore, policymakers must consider the intricate dynamics of the broader ecosystem and the interrelationships among various factors that contribute to the advancement of technological innovation in nations with lower income levels.

The results of this study highlight the significant role that institutional quality, trade openness, and education play in promoting development driven by innovation. Policymakers and practitioners can leverage the implications of these findings to develop and implement impactful strategies and policies to foster institutional reforms, facilitate trade integration, and encourage investments in education. These measures, in turn, have the potential to stimulate technological advancements and foster economic growth within lower-income countries.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest is to be disclosed.

References

- [1] Athari, S. A., The impact of financial development and technological innovations on renewable energy consumption: Do the roles of economic openness and financial stability matter in BRICS economies? *Geological Journal* **2023**, n/a, (n/a).
- [2] Baden-Fuller, C.; Haefliger, S., Business Models and Technological Innovation. *Long Range Planning* **2013**, 46, (6), 419-426.
- [3] Abid, A.; Mehmood, U.; Tariq, S.; Haq, Z. U., The effect of technological innovation, FDI, and financial development on CO2 emission: evidence from the G8 countries. *Environmental Science and Pollution Research* **2022**, 29, (8), 11654-11662.
- [4] Adebayo, T. S.; Oladipupo, S. D.; Adeshola, I.; Rjoub, H., Wavelet analysis of impact of renewable energy consumption and technological innovation on CO2 emissions: evidence from Portugal. *Environmental Science and Pollution Research* **2022**, 29, (16), 23887-23904.
- [5] Rong, G.; Qamruzzaman, M., Symmetric and asymmetric nexus between economic policy uncertainty, oil price, and renewable energy consumption in the United States, China, India, Japan, and South Korea: Does technological innovation influence? *FRONTIERS IN ENERGY RESEARCH* **2022**, 10.
- [6] Xie, Q.; Adebayo, T. S.; Irfan, M.; Altuntaş, M., Race to environmental sustainability: can renewable energy consumption and technological innovation sustain the strides for China? *Renew Energy* **2022**, 197.
- [7] Zheng, L.; Abbasi, K. R.; Salem, S.; Irfan, M.; Alvarado, R.; Lv, K., How technological innovation and institutional quality affect sectoral energy consumption in Pakistan? Fresh policy insights from novel econometric approach. *Technological Forecasting and Social Change* **2022**, 183, 121900.
- [8] Ahmed, A. D., Financial liberalization, financial development and growth linkages in Sub-Saharan African countries: An empirical investigation. *Studies in Economics and Finance* **2010**, 27, (4), 314-339.
- [9] Karim, S.; Qamruzzaman, M.; Jahan, I., Nexus between Government Debt, Globalization, FDI, Renewable Energy, and Institutional Quality in Bangladesh. *International Journal of Energy Economics and Policy* **2023**, 13, (3), 443-456.
- [10] Qamruzzaman, M.; Karim, S.; Kor, S., Does environmental degradation matter for poverty? Clarifying the nexus between FDI, environmental degradation, renewable energy, education, and poverty in Morocco and Tunisia. *Environmental Science and Pollution Research* **2023**, 30, (18), 52872-52894.
- [11] Gruber, M.; Harhoff, D.; Hoisl, K., Knowledge Recombination Across Technological Boundaries: Scientists vs. Engineers. *Management Science* **2013**, 59, (4), 837-851.
- [12] Squillace, J. In *Examination of the Financial Relationship Between Overall Stock Market Value and Corporate Investments in Privacy*, SoutheastCon 2022, 26 March-3 April 2022, 2022; 2022; pp 339-347.
- [13] Li, J.; Qamruzzaman, M., Does Tourism Induce Sustainable Human Capital Development in BRICS Through the Channel of Capital Formation and Financial Development? Evidence From Augmented ARDL With Structural Break and Fourier-TY Causality. In *Frontiers in psychology*, 2022; Vol. 13, p 804349.
- [14] Dutta, A.; Bouri, E.; Rothovius, T.; Uddin, G. S., Climate risk and green investments: New evidence. *Energy* **2023**, 265, 126376.

- [15] Yang, W.-J.; Tan, M.-Z.; Chu, S.-H.; Chen, Z., Carbon emission and financial development under the “double carbon” goal: Considering the upgrade of industrial structure. *Frontiers in Environmental Science* **2023**, 10.
- [16] Dai, M.; Qamruzzaman, M.; Hamadelneel Adow, A., An Assessment of the Impact of Natural Resource Price and Global Economic Policy Uncertainty on Financial Asset Performance: Evidence From Bitcoin. *Frontiers in Environmental Science* **2022**, 10.
- [17] Guan, C.; Qamruzzaman, M., A symmetric and asymmetric Nexus between environmental sustainability and Tourism Development in BRIC nations: what is the role of Good governance and Globalization? *Frontiers in Environmental Science* **2022**, 1663.
- [18] Shahzadi, I.; Yaseen, M. R.; Khan, M. T. I.; Makhdum, M. S. A.; Ali, Q., The nexus between research and development, renewable energy and environmental quality: Evidence from developed and developing countries. *Renewable Energy* **2022**, 190, 1089-1099.
- [19] Sarpong, K. A.; Xu, W.; Gyamfi, B. A.; Ofori, E. K., Can environmental taxes and green-energy offer carbon-free E7 economies? An empirical analysis in the framework of COP-26. *Environmental Science and Pollution Research* **2023**, 30, (18), 51726-51739.
- [20] Nketiah, E.; Song, H.; Obuobi, B.; Adu-Gyamfi, G.; Adjei, M.; Cudjoe, D., The impact of ecological footprint in West Africa: the role of biocapacity and renewable energy. *International Journal of Sustainable Development & World Ecology* **2022**, 29, (6), 514-529.
- [21] Alola, A. A.; Alola, U. V.; Akdag, S.; Yildirim, H., The role of economic freedom and clean energy in environmental sustainability: implication for the G-20 economies. *Environmental Science and Pollution Research* **2022**, 29, (24), 36608-36615.
- [22] Teece, D. J., Reflections on “Profiting from Innovation”. *Research Policy* **2006**, 35, (8), 1131-1146.
- [23] Wang, Y.; Qamruzzaman, M.; Serfraz, A.; Theivanayaki, M., Does Financial Deepening Foster Clean Energy Sustainability over Conventional Ones? Examining the Nexus between Financial Deepening, Urbanization, Institutional Quality, and Energy Consumption in China. *Sustainability* **2023**, 15, (10), 8026.
- [24] Andriamahery, A.; Qamruzzaman, M., Do Access to Finance, Technical Know-How, and Financial Literacy Offer Women Empowerment Through Women’s Entrepreneurial Development? *Frontiers in psychology* **2022**, 12, (5889).
- [25] Ma, R.; Qamruzzaman, M., Nexus between government debt, economic policy uncertainty, government spending, and governmental effectiveness in BRIC nations: Evidence for linear and nonlinear assessments. *Frontiers in Environmental Science* **2022**, 10.
- [26] Sy, M. A. N.; Maino, M. R.; Massara, M. A.; Saiz, H. P.; Sharma, P., *FinTech in Sub-Saharan African Countries: A Game Changer?* International Monetary Fund: 2019.
- [27] Hanif, I., Impact of economic growth, nonrenewable and renewable energy consumption, and urbanization on carbon emissions in Sub-Saharan Africa. *Environmental Science and Pollution Research* **2018**, 25, (15), 15057-15067.
- [28] Shi, Z.; Qamruzzaman, M., Re-visiting the role of education on poverty through the channel of financial inclusion: evidence from Lower-income and Lower Middle-income country. *Frontiers in Environmental Science* **2022**, 10, 592.
- [29] Schumpeter, J. A., The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle (1912/1934). *Transaction Publishers.–1982.–January* **1982**, 1, 244.
- [30] Qamruzzaman, M.; Wei, J., Financial Innovation, Stock Market Development, and Economic Growth: An Application of ARDL Model. *International Journal of Financial Studies* **2018**, 6, (3), 69.
- [31] Qamruzzaman, M.; Jianguo, W., Financial innovation and economic growth in Bangladesh. *Financial Innovation* **2017**, 3, (1), 1-24.
- [32] Prajogo, D. I.; McDermott, C. M., The relationship between multidimensional organizational culture and performance. *International Journal of Operations & Production Management* **2011**.
- [33] Wu, M.-Y.; Pearce, P. L.; Li, Q., Chinese behind the wheel: Factors affecting their satisfaction with international self-drive holidays. *Journal of Destination Marketing & Management* **2018**, 9, 12-19.

- [34] Ju, S.; Andriamahery, A.; Qamruzzaman, M.; Kor, S., Effects of financial development, FDI and good governance on environmental degradation in the Arab nation: Dose technological innovation matters? *Frontiers in Environmental Science* **2023**, 11.
- [35] Qamruzzaman, M.; Kler, R., Do Clean Energy and Financial Innovation Induce SME Performance? Clarifying the Nexus between Financial Innovation, Technological Innovation, Clean Energy, Environmental Degradation, and SMEs Performance in Bangladesh. *International Journal of Energy Economics and Policy* **2023**, 13, (3), 313-324.
- [36] Chen, Y.; Raza, K., Asymmetric impact of technological innovation, foreign direct investment and agricultural production on environmental degradation: evidence from Pakistan. *Environmental Science and Pollution Research* **2023**.
- [37] Ma, C.; Qamruzzaman, M., An Asymmetric Nexus between Urbanization and Technological Innovation and Environmental Sustainability in Ethiopia and Egypt: What Is the Role of Renewable Energy? *Sustainability* **2022**, 14, (13), 7639.
- [38] Xiao, Z.; Qamruzzaman, M., Nexus between green investment and technological innovation in BRI nations: What is the role of environmental sustainability and domestic investment? *Frontiers in Environmental Science* **2022**, 10.
- [39] JinRu, L.; Qamruzzaman, M.; Hangyu, W.; Kler, R., Do environmental quality, financial inclusion, and good governance ensure the FDI sustainably in Belt and Road countries? Evidence from an application of CS-ARDL and NARDL. *Frontiers in Environmental Science* **2022**, 10.
- [40] Xiao, Z.; Qamruzzaman, M., Nexus between Green investment and technological innovation in BRI nations: what is the role of Environmental Sustainability and Domestic Investment? *Frontiers in Environmental Science* **2022**, 1472.
- [41] Qamruzzaman, M., Symmetric and Asymmetric Nexus between Economic Policy Uncertainty, Oil Price and Renewable Energy Consumption in the USA, CHINA, INDIA, JAPAN, S. KORIA: Does Technological Innovation influence? *Frontiers in Energy Research* **2022**, 1746.
- [42] Raihan, A.; Muhtasim, D. A.; Farhana, S.; Pavel, M. I.; Faruk, O.; Rahman, M.; Mahmood, A., Nexus between carbon emissions, economic growth, renewable energy use, urbanization, industrialization, technological innovation, and forest area towards achieving environmental sustainability in Bangladesh. *Energy and Climate Change* **2022**, 3, 100080.
- [43] Gong, W., A study on the effects of natural resource abundance and foreign direct investment on regional eco-efficiency in China under the target of COP26. *Resources Policy* **2023**, 82, 103529.
- [44] Zhang, W.; Hong, M.; Li, J.; Li, F., An Examination of Green Credit Promoting Carbon Dioxide Emissions Reduction: A Provincial Panel Analysis of China. *Sustainability* **2021**, 13, (13), 7148.
- [45] Qamruzzaman, M., Nexus between financial developments, renewable energy consumption and environmental sustainability in Bangladesh: Evidence from ARDL and NARDL. *World Journal of Advanced Research and Reviews* **2023**, 18, (1), 1097-1113.
- [46] Raspovic, K. M.; Schaper, N. C.; Gooday, C.; Bal, A.; Bem, R.; Chhabra, A.; Hastings, M.; Holmes, C.; Petrova, N. L.; Santini Araujo, M. G.; Senneville, E.; Wukich, D. K., Diagnosis and treatment of active charcot neuro-osteoarthropathy in persons with diabetes mellitus: A systematic review. *Diabetes/Metabolism Research and Reviews* n/a, (n/a), e3653.
- [47] Islam, Y.; Mindia, P. M.; Farzana, N.; Qamruzzaman, M., Nexus between environmental sustainability, good governance, financial inclusion, and tourism development in Bangladesh: Evidence from symmetric and asymmetric investigation. *Frontiers in Environmental Science* **2023**.
- [48] Lin, J.; Qamruzzaman, M., The Impact of Environmental Disclosure and the Quality Of Financial Disclosure Quality, and IT Adoption on Firm Performance: Does Corporate Governance Ensure Sustainability? *Frontiers in Environmental Science* **2023**, 11, 23.
- [49] Akcigit, U.; Kerr, W. R., Growth through Heterogeneous Innovations. *Journal of Political Economy* **2018**, 126, (4), 1374-1443.
- [50] Sharif, A.; Kocak, S.; Khan, H. H. A.; Uzuner, G.; Tiwari, S., Demystifying the links between green technology innovation, economic growth, and environmental tax in ASEAN-6 countries: The dynamic role of green energy and green investment. *Gondwana Research* **2023**, 115, 98-106.

- [51] Acemoglu, D.; Akcigit, U.; Alp, H.; Bloom, N.; Kerr, W., Innovation, Reallocation, and Growth. *American Economic Review* **2018**, 108, (11), 3450-91.
- [52] Qamruzzaman, M.; Karim, S.; Kor, S., Does environmental degradation matter for poverty? Clarifying the nexus between FDI, environmental degradation, renewable energy, education, and poverty in Morocco and Tunisia. *Environmental Science and Pollution Research* **2023**.
- [53] Qamruzzaman, M., An asymmetric nexus between clean energy, good governance, education and inward FDI in China: Do environment and technology matter? Evidence for Chinese provincial data. *Heliyon* **2023**, 9, (5).
- [54] Serfraz, A.; Qamruzzaman, M.; Karim, S., Revisiting the Nexus between Economic Policy Uncertainty, Financial Development, and FDI Inflows in Pakistan during Covid-19: Does Clean Energy Matter? *International Journal of Energy Economics and Policy* **2023**, 13, (4), 91-101.
- [55] Andriamahery, A.; Qamruzzaman, M., Do Access to Finance, Technical Know-How, and Financial Literacy Offer Women Empowerment Through Women's Entrepreneurial Development? *Frontiers in psychology* **2022**, 12.
- [56] Anselme, A.; Qamruzzaman, M., Do access to finance, technical know-how and financial literacy offer Women empowerment through Women's entrepreneurial Sustainability? *Frontiers in psychology* **2022**, 5889.
- [57] Weixiang, S.; Qamruzzaman, M.; Rui, W.; Kler, R., An empirical assessment of Financial Literacy and Behavioural Biases on Investment Decision: Fresh Evidence from Small Investor Perception. *Frontiers in psychology* **2022**, 5746.
- [58] Huan, Y.; Qamruzzaman, M., Innovation-Led FDI Sustainability: Clarifying the Nexus between Financial Innovation, Technological Innovation, Environmental Innovation, and FDI in the BRIC Nations. *Sustainability* **2022**, 14, (23), 15732.
- [59] Qamruzzaman, M.; Wei, J., Financial Innovation and Financial Inclusion Nexus in South Asian Countries: Evidence from Symmetric and Asymmetric Panel Investigation. *International Journal of Financial Studies* **2019**, 7, (4), 61.
- [60] Qamruzzaman, M.; Jianguo, W., Investigation of the asymmetric relationship between financial innovation, banking sector development, and economic growth. *Quantitative Finance and Economics* **2018**, 2, (4), 952-980.
- [61] Kassi, D. F.; Li, Y.; Dong, Z., The mitigating effect of governance quality on the finance-renewable energy-growth nexus: Some international evidence. *International Journal of Finance & Economics* **2023**, 28, (1), 316-354.
- [62] Marco-Lajara, B.; Martínez-Falcó, J.; Sánchez-García, E.; Millan-Tudela, L. A., Analyzing the Role of Renewable Energy in Meeting the Sustainable Development Goals: A Bibliometric Analysis. *Energies* **2023**, 16, (7), 3137.
- [63] Georgatzi, V. V.; Stamboulis, Y.; Vetsikas, A., Examining the determinants of CO2 emissions caused by the transport sector: Empirical evidence from 12 European countries. *Economic Analysis and Policy* **2020**, 65, 11-20.
- [64] Abdulsalam, D. O.; Tukur, M. N., Access to Microfinance and Small Enterprise Growth in Sokoto State, Nigeria. *World Review of Business Research* **2014**, 4, (1), 62 – 75.
- [65] Liang, Z.; Qamruzzaman, M., An Asymmetric Investigation of the Nexus Between Economic Policy Uncertainty, Knowledge Spillover, Climate Change, and Green Economy: Evidence From BRIC Nations. *Frontiers in Environmental Science* **2022**, 9.
- [66] Muneeb, M. A.; Md, Q.; Ayesha, S., The Effects of Finance and Knowledge on Entrepreneurship Development: An Empirical Study from Bangladesh. *The Journal of Asian Finance, Economics and Business* **2022**, 9, (2), 409-418.
- [67] Bo, L.; Yunbao, X.; Chengbo, D.; Chao, T.; Guangde, Z.; Usman, A., Financial deepening, financial innovation, and education as new determinants of green growth in China. *Environmental Science and Pollution Research* **2023**, 30, (9), 23568-23577.
- [68] Acemoglu, D.; Linn, J., Market Size in Innovation: Theory and Evidence from the Pharmaceutical Industry*. *The Quarterly Journal of Economics* **2004**, 119, (3), 1049-1090.
- [69] Bilal, M.; Klenow, P. J., Does Schooling Cause Growth? *American Economic Review* **2000**, 90, (5), 1160-1183.
- [70] Hanushek, E. A.; Woessmann, L., Do better schools lead to more growth? Cognitive skills, economic outcomes, and causation. *Journal of Economic Growth* **2012**, 17, (4), 267-321.
- [71] Qamruzzaman, M.; Karim, S., Does public-private investment augment renewable energy consumption in BIMSTEC nations? Evidence from symmetric and asymmetric assessment. *Energy Strategy Reviews* **2023**, 49, 101169.

- [72] Hanushek, E. A.; Kimko, D. D., Schooling, Labor-Force Quality, and the Growth of Nations. *American Economic Review* **2000**, 90, (5), 1184-1208.
- [73] Li, Q.; Qamruzzaman, M., Innovation-Led Environmental Sustainability in Vietnam—Towards a Green Future. *Sustainability* **2023**, 15, (16), 12109.
- [74] Mairesse, J.; Mohnen, P., Chapter 26 - Using Innovation Surveys for Econometric Analysis. In *Handbook of the Economics of Innovation*, Hall, B. H.; Rosenberg, N., Eds. North-Holland: 2010; Vol. 2, pp 1129-1155.
- [75] Hondroyiannis, G.; Papapetrou, E.; Tsalaporta, P., New insights on the contribution of human capital to environmental degradation: Evidence from heterogeneous and cross-correlated countries. *Energy Economics* **2022**, 116, 106416.
- [76] Qamruzzaman, M., Nexus between energy intensity and Environmental Quality SSA: Evidence from GMM. *World Journal of Advanced Research and Reviews* **2022**, 16, (02), 193–210.
- [77] Shahbaz, M.; Mateev, M.; Abosedra, S.; Nasir, M. A.; Jiao, Z., Determinants of FDI in France: role of transport infrastructure, education, financial development and energy consumption. *International Journal of Finance & Economics* **2021**, 26, (1), 1351-1374.
- [78] Qamruzzaman, M., Nexus between financial development and carbon emission in Bangladesh: Evidence from ARDL and NARDL. *GSC Advanced Research and Reviews* **2023**, 14, (3), 300-312.
- [79] Adejumo, O. O.; Asongu, S. A.; Adejumo, A. V., Education enrolment rate vs employment rate: Implications for sustainable human capital development in Nigeria. *International Journal of Educational Development* **2021**, 83, 102385.
- [80] Qamruzzaman, M., Does economic policy uncertainty influences personal remittances: Evidences from AARDL and NARDL. *World Journal of Advanced Research and Reviews* **2023**, 18, (1), 014-034.
- [81] Qamruzzaman, M., Nexus between energy intensity, human capital development, Trade and environmental quality in LIC, LMIC and UMIC: Evidence from GMM. *GSC Advanced Research and Reviews* **2022**, 13, (2), 051-068.
- [82] Qamruzzaman, M., Nexus between renewable energy, foreign direct investment, and agro-productivity: The mediating role of carbon emission. *Renewable Energy* **2022**, 184, 526-540.
- [83] Qamruzzaman, M., Nexus between environmental innovation, energy efficiency and environmental sustainability in the lower-income economy. *GSC Advanced Research and Reviews* **2022**, 12, (1), 068-083.
- [84] Qamruzzaman, M., Do environmental and institutional quality attribute to inflows of FDI in Lower-Middle income Nations? Evidences from asymmetric investigation. *GSC Advanced Research and Reviews* **2023**, 15, (3), 079-104.
- [85] Pesaran, M. H., A simple panel unit root test in the presence of cross-section dependence. *Journal of Applied Econometrics* **2007**, 22, (2), 265-312.
- [86] Westerlund, J., Testing for Error Correction in Panel Data. *Oxford Bulletin of Economics and Statistics* **2007**, 69, (6), 709-748.
- [87] Kao, C., Spurious regression and residual-based tests for cointegration in panel data. *J Econom* **1999**, 90.
- [88] Pedroni, P., PANEL COINTEGRATION: ASYMPTOTIC AND FINITE SAMPLE PROPERTIES OF POOLED TIME SERIES TESTS WITH AN APPLICATION TO THE PPP HYPOTHESIS. *Econometric Theory* **2004**, 20, (3), 597-625.
- [89] Qamruzzaman, M., Nexus between environmental qualities, institutional quality and FDI inflows in Lower-income Countries. *World Journal of Advanced Research and Reviews* **2023**, 18, (3), 321-345.
- [90] Kao, C., Spurious regression and residual-based tests for cointegration in panel data. *Journal of econometrics* **1999**, 90, (1), 1-44.
- [91] Su, J.; Wang, W.; Tang, S., The spatial spillover effect of ICT development level on regional CO2 emissions. *Scientific Reports* **2023**, 13, (1), 7690.
- [92] Danish; Ulucak, R., Renewable energy, technological innovation and the environment: A novel dynamic autoregressive distributive lag simulation. *Renewable and Sustainable Energy Reviews* **2021**, 150, 111433.
- [93] Chen, M.; Sinha, A.; Hu, K.; Shah, M. I., Impact of technological innovation on energy efficiency in industry 4.0 era: Moderation of shadow economy in sustainable development. *Technological Forecasting and Social Change* **2021**, 164, 120521.

- [94] Usman, M.; Makhdam, M. S. A., What abates ecological footprint in BRICS-T region? Exploring the influence of renewable energy, non-renewable energy, agriculture, forest area and financial development. *Renewable Energy* **2021**, 179, 12-28.
- [95] Usman, M.; Hammar, N., Dynamic relationship between technological innovations, financial development, renewable energy, and ecological footprint: fresh insights based on the STIRPAT model for Asia Pacific Economic Cooperation countries. *Environmental Science and Pollution Research* **2021**, 28, (12), 15519-15536.
- [96] Zhang, Y.; Qamruzzaman, M.; Karim, S.; Jahan, I., Nexus between Economic Policy Uncertainty and Renewable Energy Consumption in BRIC Nations: The Mediating Role of Foreign Direct Investment and Financial Development. *Energies* **2021**, 14, (15), 4687.
- [97] Yingjun, Z.; Jahan, S.; Qamruzzaman, M., Access to Finance and Legal Framework in Female Entrepreneurship Development in Bangladesh: The Mediating Role of Self-Leadership. *Asian Economic and Financial Review* **2021**, 11, (9), 762-780.
- [98] Zhuo, J.; Qamruzzaman, M., Do financial development, FDI, and globalization intensify environmental degradation through the channel of energy consumption: evidence from belt and road countries. *Environmental Science and Pollution Research* **2022**, 29, (2), 2753-2772.
- [99] Zhou, M.; Li, X., Influence of green finance and renewable energy resources over the sustainable development goal of clean energy in China. *Resources Policy* **2022**, 78, 102816.
- [100] Zhang, D.; Mohsin, M.; Taghizadeh-Hesary, F., Does green finance counteract the climate change mitigation: Asymmetric effect of renewable energy investment and R&D. *Energy Economics* **2022**, 113, 106183.
- [101] Zeeshan, M.; Han, J.; Rehman, A.; Ullah, I.; Mubashir, M., Exploring the Role of Information Communication Technology and Renewable Energy in Environmental Quality of South-East Asian Emerging Economies. *Frontiers in Environmental Science* **2022**, 10.
- [102] Qamruzzaman, M., Nexus between Remittance, Trade openness and inequality in South Asian countries: New evidence from the nonlinear unit root, nonlinear OLS, and NARDL, and asymmetry causality test. *Contaduría y Administración* **2021**, 66, (4), 1-27.
- [103] Odhiambo, N. M., Trade openness and energy consumption in sub-Saharan African countries: A multivariate panel Granger causality test. *Energy Reports* **2021**, 7, 7082-7089.
- [104] Xia, W.; Apergis, N.; Bashir, M. F.; Ghosh, S.; Doğan, B.; Shahzad, U., Investigating the role of globalization, and energy consumption for environmental externalities: Empirical evidence from developed and developing economies. *Renewable Energy* **2022**, 183, 219-228.
- [105] Weixiang, S.; Qamruzzaman, M.; Rui, W.; Kler, R., An empirical assessment of financial literacy and behavioral biases on investment decision: Fresh evidence from small investor perception. *Frontiers in psychology* **2022**, 13.
- [106] Udeagha, M. C.; Ngepah, N., Does trade openness mitigate the environmental degradation in South Africa? *Environmental Science and Pollution Research* **2022**, 29, (13), 19352-19377.
- [107] han, J.; Zeeshan, M.; Ullah, I.; Rehman, A.; Afridi, F. E. A., Trade openness and urbanization impact on renewable and non-renewable energy consumption in China. *Environmental Science and Pollution Research* **2022**, 29, (27), 41653-41668.
- [108] Murshed, M.; Chadni, M. H.; Ferdous, J., Does ICT trade facilitate renewable energy transition and environmental sustainability? Evidence from Bangladesh, India, Pakistan, Sri Lanka, Nepal and Maldives. *Energy, Ecology and Environment* **2020**, 5, (6), 470-495.
- [109] Gnanon, S. K., Trade Openness and Diversification of External Financial Flows for Development: An Empirical Analysis. *South Asian Journal of Macroeconomics and Public Finance* **2020**, 9, (1), 22-57.
- [110] Abubakar, A.; Kassim, S. H.; Yusoff, M. B., Financial development, human capital accumulation and economic growth: empirical evidence from the Economic Community of West African States (ECOWAS). *Procedia-Social and Behavioral Sciences* **2015**, 172, 96-103.
- [111] Md Qamruzzaman, S. N., Ananda Bardhan, Nexus between Remittance, Financial Volatility, Trade Openness, Money Supply, and Non-Performing Loan: An Application of Autoregressive Distributed Lagged (ARDL) Model. *Journal of Banking and Finance Management* **2021**, 3, (2), 34-54.

- [112] Md, Q.; Muneeb, M. A.; Rimsha, K.; Ayesha, S.; Hina, S., Symmetric and Asymmetric Effects of Financial Innovation and FDI on Exchange Rate Volatility: Evidence from South Asian Countries. *The Journal of Asian Finance, Economics and Business* **2021**, 8, (1), 23-36.
- [113] García, M. A.; Farías, E. B.; Mendoza, Y. F., Environmental Education Based on the Analysis of the Social Recovery Mechanisms Implemented Post-COVID. *Revista de Gestão Social e Ambiental* **2023**, 17, (3), e03492.
- [114] Zhou, R.; Lee, N., The Reception of Education for Sustainable Development (ESD) in China: A Historical Review. *Sustainability* **2022**, 14, (7), 4333.
- [115] Shi, Z.; Qamruzzaman, M., Re-Visiting the Role of Education on Poverty Through the Channel of Financial Inclusion: Evidence From Lower-Income and Lower-Middle-Income Countries. *Frontiers in Environmental Science* **2022**, 10.
- [116] Pantelopoulos, G., Higher education, gender, and foreign direct investment: Evidence from OECD countries. *Industry and Higher Education* **2022**, 36, (1), 86-93.
- [117] Musah, M.; Owusu-Akomeah, M.; Kumah, E. A.; Mensah, I. A.; Nyeadi, J. D.; Murshed, M.; Alfred, M., Green investments, financial development, and environmental quality in Ghana: evidence from the novel dynamic ARDL simulations approach. *Environmental Science and Pollution Research* **2022**, 29, (21), 31972-32001.
- [118] Mele, M.; Magazzino, C.; Schneider, N.; Gurrieri, A. R.; Golpira, H., Innovation, income, and waste disposal operations in Korea: evidence from a spectral granger causality analysis and artificial neural networks experiments. *Econ Politica* **2022**, 39.
- [119] Li, Y.; Alharthi, M.; Ahmad, I.; Hanif, I.; Hassan, M. U., Nexus between renewable energy, natural resources and carbon emissions under the shadow of transboundary trade relationship from South East Asian economies. *Energy Strategy Reviews* **2022**, 41, 100855.
- [120] Lei, W.; Liu, L.; Hafeez, M.; Sohail, S., Do economic policy uncertainty and financial development influence the renewable energy consumption levels in China? *Environmental Science and Pollution Research* **2022**, 29, (5), 7907-7916.
- [121] Pu, G.; Qamruzzaman, M.; Mehta, A. M.; Naqvi, F. N.; Karim, S., Innovative Finance, Technological Adaptation and SMEs Sustainability: The Mediating Role of Government Support during COVID-19 Pandemic. *Sustainability* **2021**, 13, (16), 9218.
- [122] Ganlin, P.; Qamruzzaman, M.; Mehta, A. M.; Naqvi, F. N.; Karim, S., Innovative Finance, Technological Adaptation and SMEs Sustainability: The Mediating Role of Government Support during COVID-19 Pandemic. *Sustainability* **2021**, 13, (16), 1-27.
- [123] Fang, L.; Qamruzzaman, M., An Asymmetric Investigation of Remittance and Trade Openness Impact on Inequality: Evidence From Selected South Asian Countries. *Frontiers in psychology* **2021**, 12.
- [124] Qamruzzaman, M.; Karim, S., ICT investment impact on human capital development through the channel of financial development in Bangladesh: An investigation of quantile ARDL and Toda-Yamamoto test. *Academic Journal of Interdisciplinary Studies* **2020**, 9, (5), 112-112.
- [125] Musakwa, M. T.; Odhiambo, N. M., The causal relationship between remittance and poverty in South Africa: A multivariate approach. *International Social Science Journal* **2021**, 71, (239-240), 37-48.
- [126] Musa, M. S.; Jelilov, G.; Iorember, P. T.; Usman, O., Effects of tourism, financial development, and renewable energy on environmental performance in EU-28: does institutional quality matter? *Environmental Science and Pollution Research* **2021**, 28, (38), 53328-53339.
- [127] Wang, R.; Mirza, N.; Vasbieva, D. G.; Abbas, Q.; Xiong, D., The nexus of carbon emissions, financial development, renewable energy consumption, and technological innovation: What should be the priorities in light of COP 21 Agreements? *Journal of Environmental Management* **2020**, 271, 111027.
- [128] Wang, Q.; Xiao, K.; Lu, Z., Does economic policy uncertainty affect CO2 emissions? Empirical evidence from the United States. *Sustainability* **2020**, 12, (21), 9108.
- [129] Qamruzzaman, M.; Karim, S., Do Remittance and Financial Innovation causes stock price through Financial Development: An Application of Nonlinear Framework. **2020**.
- [130] Qamruzzaman, M.; Jianguo, W., Nexus between remittance and household consumption: fresh evidence from symmetric or asymmetric investigation. *Journal of Economic Development* **2020**, 45, (3).

- [131] Qamruzzaman, M.; Mehta, A. M.; Naqvi, F. N., Nexus between Uncertainty, Remittances, and Households Consumption: Evidence from Dynamic SUR application. *Frontiers in Environmental Science* **2022**, 1546.
- [132] Qamruzzaman, M.; Karim, S.; Jahan, I., INNOVATION AND SUSTAINABLE GROWTH OF SMES IN BANGLADESH - DO FINANCIAL INNOVATIONS MATTERS: AN ASYMMETRIC INVESTIGATION. *Academy of Entrepreneurship Journal* **2022**, 28, (S4), 1-28.
- [133] Qamruzzaman, M., Nexus between foreign direct investments renewable energy consumption: What is the role of Government debt? *International Journal of Multidisciplinary Research and Growth Evaluation. 2022b* **2022**, 3, (3), 514-522.
- [134] Md, Q., Nexus between environmental innovation, energy efficiency and environmental sustainability in the lower-income economy. *GSC Advanced Research and Reviews* **2022**, 12, (1), 068-083.