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Do technological innovation, foreign investment, trade and human capital have a symmetric effect on economic growth? Novel dynamic ARDL simulation study on Bangladesh

Preethu Rahman[1] · **Zhihe Zhang**[1] · **Mohammad Musa**[1]

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Abstract

Bangladesh's economy has flourished a great deal during recent years, establishing itself as an enthralling market. This country's remarkable growth trajectory can be attributed to technological innovation, foreign direct investment, trade and human capital, all of which have significant impacts on its economic growth. Bangladesh's economic development has been poorly explored in previous studies due to the lack of integration between these dynamics. Does the question arise whether this growth factors have a symmetrical or non-symmetrical effect on Bangladesh's economic growth and policymaking? We conducted this study with the primary objective of evaluating how technological innovation, foreign direct investment, trade, and human capital affect Bangladesh's economic development. Based on time series data years spanning 1990 to 2020, this study used the dynamic ARDL simulation method to accomplish its objective. This novel approach allows users to examine possible counterfactual changes in variables based on the ceteris paribus theory, as well as to test cointegration, long- and short-run symmetric associations between variables. Research findings indicate that technological innovation and human capital have a long-run symmetric relationship with Bangladesh's economic development. There is a significant correlation found between economic growth and all variables in the short run. To further check the robustness of the study we employed the nonlinear ARDL approach. Therefore, this study can undoubtedly be used by policymakers and the government as a basis for prioritizing and encouraging critical policy changes that will improve Bangladesh's economic development.

Keywords Technological innovation · Foreign direct investment · Trade openness · Human capital · Economic growth · Dynamic ARDL simulations

✉ Zhihe Zhang
zhihe_zhang@163.com

Extended author information available on the last page of the article

JEL Classification O1 · O2 · O3 · O4

1 Introduction

New ideas are brought to life through technological innovation by modification of existing ones or restoration of old ones. With the improvement of innovation efficiency, more goods and services are distributed to the public and the economy grows (Taques et al. 2021). By utilizing technological innovation, a country's competitive advantage can be fully maximized, resulting in high returns for capital, facilitating imports of intermediate goods, and enhancing returns to capital in less developed economies, such as Bangladesh. Researchers and policy makers have long been interested in technological innovation because it contributes to economic growth, job creation, and societal development (Mohamed et al. 2021). Therefore, new innovations are created and carried out in a socio-cultural framework and economic growth is considered a prerequisite for improving living standards and life opportunities in the future world (Skare and Porada-Rochon 2022). An innovative economy ensures economic growth and execution, tackling global concerns through product developments and service delivery, boosting efficiency, creating innovative jobs, and enhancing the quality of life of people around the world (Ascani et al. 2020). It has been a long-term focus of experts to build a bridge between economic growth and innovation (Zhou et al. 2022). The input and output dimensions of technological innovation are equally important. As Bangladesh's economic development has improved over the past few years, the world media has become increasingly positive about its progress, the country gained an additional 8% of per capita income in the fiscal year 2020–21 (Brende 2022). By enhancing the effectiveness of capital in production through technical changes in capital assets, technological progress stimulates economic growth by compensating for capital losses, increasing efficiency in capital production, and increasing the spread of knowledge in society, ultimately increasing economic productivity (Taques et al. 2021). It can be interesting to note that both less developed and developed countries are able to benefit from innovation. Research shows, foreign direct investment significantly increased productivity of the factors of production, as well as the availability of expert labors, thereby boosting economic growth in Southeast Asian countries (Sun et al. 2022). In recent years, foreign direct investment has evolved in order to include, in addition to money transfers, the transfer of technology, management capabilities, skills, marketing, and other intangible assets (Saleem et al. 2020). Consequently, innovation in technology relies heavily on human resources, and how they are managed and developed affects it greatly. Economic policy should promote economic prosperity and growth in order to achieve its ultimate goals and also corrects labor market imbalances and builds new productive capacities (Mohamed et al. 2021). In addition, Trade openness stimulates innovation and entrepreneurship by increasing competition and market access (Udeagha and Ngepah 2022b). Economic empowerment and innovation are the two most important tools for Bangladesh to flourish in the future. We choose to analyze the effects of above-mentioned microeconomic factors and see how they impact on economic growth of Bangladesh. In order to advance everyday-life at

home, at work, in business, and in society, the government plays a crucial role as a facilitator and as a creator of an environment that fosters creativity. Bangladesh is deemed from lower-middle-income to middle-income country ranked in 2015 by the World Bank (Kamal Uddin 2021). It is now one of the fastest-growing countries, and we can identify some of the benefits and drawbacks from such a quick pace of expansion. The country has made tremendous progress in decreasing extreme poverty, and its per capita income might soon climb more.

Our research interest in Bangladesh's technological innovation, foreign direct investment, human capital and trade and their relation with its economic development arose after revealing that Bangladesh's overall capacity for innovation and creativity had remained behind for years. The research gap is found accurate as the previous studies are based on literature works or yielded mostly conflicting results. The unavailability of critical research data is a significant disadvantage for any research. Bangladesh was ranked 116th out of 131 economies by the World Intellectual Property Organization report based on overall innovation indicators (Cornell University 2020). Global financial liberalism is measured by the Global Innovation Index (GII) using 80 innovation indicators. Bangladesh's performance on innovation shows a gradual decrease, according to the GII report in 2020. It comes in at 119th in terms of innovation inputs and 114th in terms of innovation outputs (Dutta et al. 2021). Sadly, Bangladesh's status in these disciplines has declined in recent years. Bangladesh is ranked 24th out of 29 low-income nations and 10th out of 10 in Central and Southern Asia. According to the GII, Bangladesh has underperformed in innovation and development. Each of the GII's seven assessment pillars—institution, human capital and research, infrastructure, market superiority, business complexity, knowledge and technology—scored worse than the worldwide average. While conducting this research, we could not locate research and development data for 31 consecutive years in the World Development Indicator or other databases, which could be highly beneficial in determining Bangladesh's innovativeness and innovation capacity. Drawbacks of our research reveals Bangladesh requires special attention in innovation, economic research, and data accessibility. It must reassign and examine why its performance in the GII has remained consistently low. Bangladesh's past three-year economic data and GII ranking study suggests that a comparable data set was reused. This may be one of the reasons for its continued decline. Studies by different organizations and researchers related to poor innovation capacity has piqued our curiosity in researching and determining the cause of this phenomenon. Some of Bangladesh's government policies are anti-innovation. High taxes on machinery and replacement parts imports creates obstacle conducting business in Bangladesh, new enterprises are hesitant to enter. Bangladesh studies on innovation are very weak (Uddin and Ahmed 2021). Bangladesh's unstable government and political revolutions have a higher failure rate that hampered the construction of good management and overall development (Kabadurmus 2021). Bangladesh has yet to notice a shift in policy. Bangladesh should have centralized or decentralized intellectual property policies that foster creativity and innovation (Murshed and Alam 2021). The accomplishment of a rapid innovation cycle can be made considerably easier if academics, government, and the public and commercial sectors collaborate (Tashmina 2019). Therefore, in this study, a range of economic indicators, including patents, foreign direct investment, trade openness, and human capital, will be used to examine

the impact of technological innovation on economic growth. A novel methodology is employed, which is newly established and provides more robust results. Popular estimation system, developed by Jordan and Philips (2018), the Dynamic Autoregressive Distributed Lag (DYNARDL) simulations that is gaining more recognition, as time series data are increasingly used in economics.

However, after analyzing the literatures in recent decades, it has found only a few empirical studies that have explicitly explored regarding the relevance of technological innovation, foreign direct investment, trade openness, and human capital with economic growth of Bangladesh and also the variables are not incorporated together which have generated mostly conflicting results. There is an increasingly large body of research on the beneficial effects of different growth proxies on the economy. The vast majority of these studies assume that there is only one dimension of relationship between the regressor and the regressed, either a negative or positive relationship, long or short run. Taking those study gaps into consideration, the current study makes a big difference compared to previous studies, by contributing: First, the identification of technological innovation is critical to constructing and planning strategies for Bangladesh's developing economy, which is currently experiencing a significant increase. It is, however, rare for this country to investigate the consequences of technological innovation on its economy. We are also aware of no study so far incorporates potential factors such as patents, foreign direct investment, trade, and education expenditure together into its empirical assessment of the dynamic relationship between the factors and economic development. This is an important gap our study intends to fill. Second, this paper analyzes both symmetrical and non-symmetrical relationships between the variables, considered as an important highlight. In previous studies, the ARDL approach by Pesaran et al. (2001) were widely employed, which only compute and examine short- and long-term relationships between variables. Although several limitations do exist (Jordan and Philips 2018) have developed a dynamic ARDL simulation model designed to address some of them. In this study, a dynamic ARDL simulation model is incorporated into the methodological literature. The novel dynamic ARDL simulations can resolve prevailing difficulties and interpret results in a more effective and efficient manner than using simple ARDLs. In addition to simulating and plotting the variables, this framework can estimate their long- and short-term relationships and predict graphs of symmetric and asymmetric changes. Our results are therefore considered accurate and unbiased when we adapt this method to this study. Fourth, to further check the robustness of the study we employed the nonlinear ARDL approach. We are aware of no previous studies that have used all these linear, nonlinear and dynamic simulation tests together in the Innovation, FDI, Trade, Human capital and Economic growth nexus especially in the context of Bangladesh.

2 Literature review

A substantial body of research has focused on several variables affecting economic growth in Bangladesh, including technological innovation, foreign investment, trade openness, human capital, and other mediating factors that are believed to influence

economic growth. As part of the analysis of the effects of the factors mentioned above on the economy, researchers are increasingly conducting investigations into the factors affecting the elements. The issues that researchers are addressing are that the economic construction of a society may expand over time to meet its needs, increasing the economy's ability to produce goods and services. A sustainable economic growth in the country results in a higher national income and more employment, resulting in a higher standard of living (Mohamed et al. 2022). Therefore, the literature review part is broken down following (Udeagha and Ngepah 2022a, b, c) into four sub-sections. For a full understanding of the relationship between technological innovation, foreign direct investment, trade openness, human capital, and economic growth, in context of Bangladesh, this research has considered them simultaneously. A wide range of literature has been written about the role that these variables can play in promoting economic growth. We contribute to the literature in the following ways: First, it is the first study that found the symmetric, asymmetrical, and dynamic relationship between technological innovation, foreign direct investment, trade openness, human capital, and Bangladesh economic growth. As a second step, to provide a clear presentation of our literature study, by breaking down the sections into: (a) technological innovation and economic growth nexus, (b) foreign direct investment and economic growth nexus, (c) trade openness and economic growth nexus, and (d) human capital and economic growth nexus. Finally, we quantified this based on analytical methods used in long- and short-term studies of previous researches. Consequently, we were able to compare our predicted results with the long- and short-term results of previous studies.

2.1 Technological innovation and economic growth nexus

Historically, technological innovation has made a significant contribution to economic growth, new jobs, and societal well-being and always attracted researchers and policy makers. Innovation in technology creates opportunity for both developed and less developed countries, and people's ability to create innovative technologies and ideas contributes to human development in all areas (Mohamed et al. 2021). Innovation is considered to be a critical factor of economic growth, since a higher level and higher-quality of innovation leads to a higher rate of economic growth (Abdellaoui and Mekhzoumi 2020). In order to increase the investment capacity, countries increase their balance of payments and compensate for their lack of national savings. Most developed and developing countries consider innovation as one of the strongest pillars of their development strategies (Liao et al. 2021). Innovative factors stimulates increased entrepreneurship by increasing competition and market access. As trade openness improves integration with innovation sources, foreign direct investment increases gains, and economies are able to take advantage of increased returns to scale and efficiencies of specialization, economic growth is improved (Udeagha and Ngepah 2022b). Despite most people believing that natural resources supply most of a country's income, human capital is considered an important factor in terms of economic development (Kabadurmus 2021). An economy with a skilled workforce and a positive growth outlook tends to follow the various

economic motivations. Developing countries are intrinsically linked to technology transfer from advanced countries through trade, foreign direct investment, capital imports, intermediate goods, machinery, and other means, so that resources can be preserved for future generations while economic and social growth is achieved (Zhangqi et al. 2022). Due to globalization, technological differences are explaining the differences in economic growth and income inequality between countries. Using more efficient technologies will lead to lower costs and increased productivity, so this will help companies and individuals make the most of the technology (Tseng 2022). Technology, innovation and economic growth have been examined in a number of recent studies, and numerous examples of countries were studied with a positive influence of technological innovation on their economic growth. Mohamed et al. (2022) applied the error correction model (ECM) method, together with co-integration tests and Granger's causality test to measure how technological innovation has affected economic growth in developing countries. Another research by Mohamed et al. (2021) examined the relationship between technological innovation, foreign direct investment, and economic growth in Egypt between 1990 and 2019, utilizing a simultaneous integration test of the autoregressive distributed lag model. There are statistically significant results both over long and short horizons in the model, showing a joint complementary relationship between GDP per capita and the independent variables. A total of nine countries have been included in the analysis of Abdellaoui and Mekhzoumi (2020) for the period 2007–2016 in order to understand the impact of innovation on economic development. Having used the seemingly unrelated regression equations (SURE) model and the mean group panel method for measuring economic data, it was concluded that innovation improves GDP and unemployment. In new economics, knowledge and ideas are considered final factors of production instead of land, labor, and capital, which were considered final factors of production by traditional economists; superior growth is associated with creativity (Su et al. 2022). A number of important tools are available for supporting technological advancements, including investments in scientific research and development, education, and restoration of human capital (Ramkumar et al. 2022). In response to the globalization of the economy and the opening of distribution markets, countries need to improve their competitiveness in order to be able to export and invest more. Through technology transfer, this contributes to narrowing the technological gap between developed and developing countries (Guo et al. 2021).

2.2 Foreign direct investment (FDI) and economic growth nexus

Throughout the world, foreign direct investment is important for transferring new technologies to host countries, which in turn contributes to greater productivity and economic growth. Therefore, this spread has primarily been achieved by multinational companies interacting with local suppliers and customers, as well as by local manufacturers imitating technology and knowledge in competition with these companies (Abdellaoui and Mekhzoumi 2020). Foreign direct investment is always accounted for an important part of economic growth. The relationship of FDI toward economy is taken positive and significant (Sirén et al. 2020). FDI has led to the

acquisition of foreign technology by many developing countries, however, the evidence suggests that the increase in productivity has not necessarily been as expected (Elkomy et al. 2021). Developing countries benefit indirectly from the transfer of technology associated with international companies by encouraging them to invest. The impact of technology that stimulates economic growth depends on how it contributes to local company profitability. There are positive external effects associated with foreign direct investment, as well as how much modern technology applied by local companies in host countries is able to substitute or complement it (Xu et al. 2022). Toward this end, Bangladesh is undertaking efforts to attract more direct foreign investment, utilizing advanced technology and company formation management skills in an effort to obtain foreign capital. In their study (Ullah et al. 2022) examined FDI inflow and Institutions' Quality (IQ), focusing on how institutions influence FDI and economic growth using a larger dataset of 80 countries in developing regions, including Asia, Latin America, the Caribbean, and Sub-Saharan Africa (SSA).The authors used the Generalized Method of Moment to estimate a dynamic panel model. According to their research, FDI inflows and IQ both have a significant impact on rapid economic growth, but FDI-led economic growth is higher in Asian and SSA countries, and the interaction between FDI and IQ also had a greater effect on Asian countries' economic growth. It is widely known in the theoretical literature that FDI and economic growth nexus has positive effects, but empirical investigations have led to mixed conclusions after studying how technology plays a role in this relationship found by Liao et al. (2021). Based on an analysis of data from 83 countries from 1990 to 2012, the author concluded that foreign direct investment had a positive and significant effect on economic growth in only middle- and high-income countries, while low-income countries did not experience a positive impact. Elkomy et al. (2021) studied the role of foreign technology in Egypt's manufacturing industries during 2006–2009 in order to identify the main driver of domestic productivity growth. According to the study, only technologically intensive industries are capable of effectively absorbing foreign technology in Egypt. Foreign investment can increase the host country's export volume by increasing its foreign currency revenue when foreign investors acquire local inputs and sell them to local enterprises. In recent years, FDI flows into developing nations have remained constant, growing by roughly 2% and the global FDI has increased to 54% (Sirén et al. 2020). According to UNCTAD's World Investment Report published in 2019, Bangladesh received $3.61 billion foreign direct investment in 2018, representing an increase of 68% over the previous year. Bangladesh's foreign direct investment intake has surged due to significant investments in electricity generation and labor-intensive sectors. Bangladesh acknowledged $1.15 billion in foreign direct investment in the first six months of 2020, a decrease of 31.79 percent from the same period last year that is the net overseas investment decreased to $1.15 billion, down 31.79 percent from $1.69 billion in a similar period last year, according to the Bangladesh Bank's short-term data collection (Ibrahim Hossain Ovi 2020). Because of the tremendous impact of the Covid-19 epidemic, both global and Bangladeshi foreign direct investment flows have decreased. In response to the Covid-19 outbreak, global foreign direct investment has plummeted by 49% (Dutta et al. 2021). The global economic slowdown has obstructed national investments, and a prolonged recession has forced

businesses to consider new endeavors. Mahmud et al. (2018) provides an overview of Bangladesh's development experience that a number of country-specific mechanisms, i.e., significant investments in infrastructure, and a widespread penetration of non-governmental organizations into rural communities have contributed to Bangladesh's success in accelerated development. Assuring clarity and consistency in investment policies and creating a stable economic and investing environment is an important part of attracting foreign direct investment (Munyanyi 2017).

2.3 Trade openness and economic growth nexus

Generally, there is a fairly consistent view on the relationship between trade openness and economic growth. Within foreign economic theory circles, an open trade economy can facilitate improved economic growth, capital formation, and resource allocation, thereby facilitating economic growth improvement (Akbulut Yıldız, 2020). Economic growth quality can be significantly boosted by trade opening, both short and long term. When the short-term fluctuations divergence from the long-term equilibrium, economic growth quality can be automatically adjusted to maintain stability. There were significant regional heterogeneities and nonlinear threshold characteristics that influenced trade openness' impact on quality of economic growth (Kong et al. 2021). During the period 1984–2017, a study conducted by Omoke and Opuala Charles (2021) used three measures of trade openness: total trade, import trade, and export trade. The results of the ARDL bounds test suggest long-term cointegration between the variables. Based on research by Udeagha and Ngepah (2021) it has been shown that a positive and negative partial sum decomposition of trade openness can be used to test short- and long-run nonlinearities. The effect of trade openness on economic growth is asymmetric in the short and long run. Several scholars have also concluded that countries involved in international trade are more productive, and thus tend to develop more rapidly than countries that produce solely for domestic consumption. A study of trade and GDP growth in developed and developing countries between 1980 and 2014, using GMM estimator developed for dynamic panel data models is conducted by Fatima et al. (2020) when human capital accumulation (HCA) is accounted for as an intervening variable. 19 Middle Eastern and North African countries from 1999 to 2012 are studied by Kalai and Zghidi (2019) where the authors used autoregressive distributed lag test in order to analyze cointegration between foreign direct investment, international trade, and economic growth. The dynamic growth model was applied to 42 Sub-Saharan African countries between 1980 and 2012 by Zahonogo (2016) while the author studied effects of trade openness on economic growth. Based on long-run equilibrium relations, the Pooled Mean Group estimation technique is applied to dynamic heterogeneous panels and the empirical evidence indicates that trade openness positively impacts economic growth below a trade threshold and negatively impacts growth above it. The world economy has experienced continuous growth for the past two centuries, accompanied by an even faster increase in global trade. Similarly, looking at country-level statistics for the last half-century reveals a relationship between economic growth and trade (Udeagha and Ngepah 2022b). A country's trade openness

can lead to growth through specialization, innovation, productivity enhancement, or improved resource allocation, according to traditional trade theory. Developing and developed countries trade freely with each other, thereby transferring knowledge between them, which implies a skilled domestic labor force is needed to adapt new technologies (Kabadurmus 2021).

2.4 Human capital and economic growth nexus

As a high-potential developing country, whose economic success has been outstanding, Bangladesh uses labor-intensive procedures, so it is vital to know how innovation efforts affect labor performance and thus influence the economy. Through the development of the public and private sectors as well as improvements in people's living conditions, we can ensure the level of education of the workforce, investment in research, and creation of new products. Using the Ordinary Least Square (OLS) method, Krokeyi and Niyekpemi (2022) examine the impact of human capital development on Nigerian economic growth from 1981 to 2018. Specifically, they examine the effect of government spending on education, health, and economic growth. In Nigeria, government expenditure on education has a statistical and significant impact on real GDP and determines the direction of causality between human capital variables and economic growth. As a result of the threshold model, Apergis et al. (2022) shows that the human capital-growth nexus has a threshold effect. Nevertheless, once a certain level of governance has been achieved, the relationship turns out to be positive. Despite weakly positive relationships between human capital and economic growth, their findings indicate that they are weakly positive up to a certain level of governance. In order to achieve higher economic growth, institutional quality differences can be explained by the mixed evidence on the human capital–growth relationship, and the findings suggest that better governance contributes to the productive use of human capital. According to Keji (2021), economic growth in Nigeria is correlated with human capital between 1981 and 2017. Keji used vector autoregressive and Johansen techniques to analyze the relationship. The estimated coefficients of human capital indicate a significant long-run influence on the growth of the Nigerian economy. In their study, Zhang et al. (2021) utilized the dynamic autoregressive distribution lag (DARDL) approach to examine the relationship between natural resources, human capital, and economic growth in Pakistan from 1985 to 2018. The analysis indicates that human capital, natural resources, and economic growth have a negative relationship with carbon emissions over the long run. Additionally, in the short run, both human capital and economic growth are positively correlated with carbon emissions, whereas natural resources are negatively correlated with carbon emissions. Human capital and economic growth nexus are shown to have a mixed correlation in these studies, highlighting the puzzle surrounding the correlations between the two. Human capital development along with highly educated labor force are critical to raising productivity levels within the economy as a whole. Developing human capital is the most significant aspect of transitioning a traditional economy to a knowledge-based economy (Qamruzzaman 2017). Increasing wages for educated workers promotes the adoption of technology, while increasing

wages for non-educated workers retards it. When education costs are too high, the economy may become stagnant (Khatoon et al. 2021). According to statistical analysis, education structures in East Asia are formed and expanded in direct proportion to economic progress. The economic expansion increases demand for enhanced education systems and higher education. Developing countries can achieve economic growth by narrowing the technical divide with advanced ones. Indeed, it appears as though the complementarity of education and other features is the powerful force behind economic advancement (Klofsten et al. 2021). Due to demographic and economic changes, Bangladesh has gradually increased its demand for postsecondary education, resulting in higher standards for education. Bangladesh's education system still has a long way to go before it can compete on a global scale, according to the ADB (2019). Universities in Bangladesh rank lower than the worldwide average for higher education, hindering graduates' employment prospects. University research aims to undermine student capacity, qualified teachers are in short supply, as are opportunities for professional growth, recent graduate employment polls reveal that the job market for tertiary graduates is extremely challenging. Approximately a third of graduates stay unemployed after graduation for one or two years. Employers value polytechnic graduates' technical skills and applied skills training (Mercy 2019). Higher education rankings are becoming an increasingly accepted indicator of academic quality and graduate reputation and till today. No Bangladeshi university has been ranked among the top 100 universities globally in international rankings (Khazaei et al. 2021).

2.5 Summarizing literature gaps

Given the widespread prominence of earlier efforts, a number of important areas of knowledge have been overlooked; this investigation seeks to address these inadequacies. In summary, our review of the literature suggests that relatively few studies have used the innovation growth factors together paired with econometric analyses as selected for this paper. No research has been conducted in Bangladesh concerning the deep interaction between technological innovation and growth factors to shed light on the precise mechanisms through which this linkage could operate. Studies have independently focused on one variable and attempted to find their relationships or effects on economic growth based on the literature available. A relatively small number of studies have examined this relationship by using the appropriate model, such as the endogenous growth model, instead of a variety of models. It would be inaccurate to draw empirical conclusions if they only consider economic and social factors as influencing factors. The effects of all these factors on a country's economy are well known, but it would be more informative if they were studied in a particular region like Bangladesh to determine whether their effects vary when combined. The study of the effects of technology, investment, trade, and human capital factors on the economy has always been important, and the study is becoming increasingly comprehensive. With the time series data spanning 1990 to 2020, we intended to study in depth all the factors that influence Bangladesh's economy. Due to the lack of data in WDI database for the years 2021 and 2022, these years were excluded

from the study. Furthermore, this study utilized comprehensive and leading econometric analysis techniques to quantify these interactions based on previously identified gaps.

3 Material and methods

Our study has aimed to estimate Bangladesh's economic development in terms of technological innovation, foreign direct investment, trade openness and human capital applying dynamic ARDL simulations model by Jordan and Philips (2018) developed for time series cointegration analysis to address issues with the traditional ARDL method. This simulation procedure provides a means of demonstrating changes in the independent variables and their effects on the dependent variables while keeping the residual variables constant in the equation through mechanical measurements, simulations, and drawing figures. Simulations using Dynamic ARDL can be used to examine equilibrium relationships in the long run and in the short run, at levels and differences (Sarkodie and Owusu 2020). It is necessary to conduct a stationarity test before implementing the dynamic ARDL simulation model in order to determine how the variables are integrated. Therefore, in the current research, the series' integration order was determined by Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests. The study further employs unit root test developed by (Zivot and Andrews 1992) to address the issue of structural break in series. The ARDL bounds test reveals the results of the SIC's lag length selection criteria. These tests are particularly sensitive to autocorrelation since they are based on serially uncorrelated errors to ensure validity. Using the standard but modified ARDL bounds test with surface regression is appropriate when the dependent variable violates the initial conditions. To account for potential heteroskedasticity, we generate the variables in either percentage form or natural logarithms. For testing the robustness of the study, we used the newly developed nonlinear autoregressive distributed lags (NARDL) framework. Finally, model stability tests are conducted (Fig.1).

4 Model construction

4.1 Model specification and functional form

In order to describe the relationship between technological innovation, foreign direct investment, trade, and human capital, this study uses the following equation,

$$\begin{aligned} \mathrm{LNGDPPC}_{it} = {} & \alpha + \beta_1 \mathrm{LNPATENT}_{it} + \beta_2 \mathrm{LNFDI}_{it} \\ & + \beta_3 \mathrm{LNTRADE}_{it} + \beta_4 \mathrm{LNEDU\_EXP}_{it} + \varepsilon_{it} \end{aligned} \tag{1}$$

where LNGDPPC is the natural logarithm of dependent variable. LNPATENT represents technological innovation, LNFDI is for the foreign direct investment, LNTRADE denotes trade openness and LNEDU_EXP represents the education

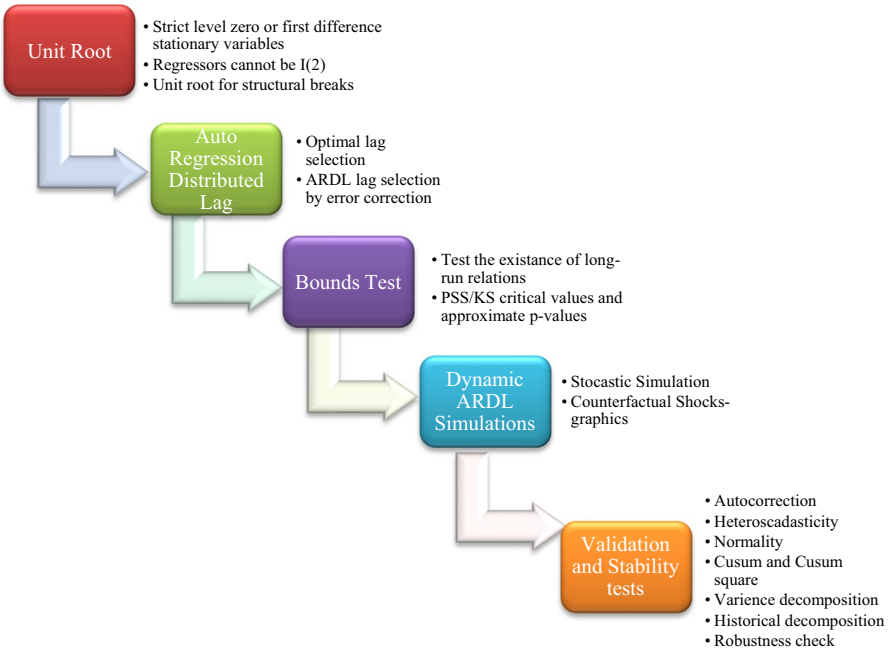

Fig. 1 Model framework

expenditure, $i = 1$, $t = 1$, α is the constant. β_1, β_2, β_3 and β_4 are the different elasticities and ϵ_{it} is the error terms.

The Augmented dickey–fuller (ADF) (Dickey and Fuller 1979) and Phillip–Perron (PP) (Phillips and Perron 1988) unit root tests with intercept and trend are performed independently; the Schwarz information criteria (SIC) are used to determine the best lag lengths. The appropriate lag length is 1 and 3. The ADF test is used for serial correlation in the error term, adding lagged difference of dependent variable. The ADF unit root equation is given below in (2) and Phillip–Perron unit root formula used is given at (3)

$$\Delta y_t = \alpha y_{t-1} + x_t'\delta + \beta_1 \Delta y_{t-1} + \beta_2 \Delta y_{t-2} + ... + \beta_\rho \Delta y_{t-\rho} + \nu_t \tag{2}$$

$$t_\alpha = t_\alpha \left(\frac{\gamma_0}{f_0}\right)^{1/2} - \frac{T\left(f_0 - \gamma_0\right)(se(\hat{\alpha}))}{2f_0^{1/2}s} \tag{3}$$

In this study, Zivot and Andrews (1992) unit root test is used which enables the determination of structural break internally, obtaining the following Eq. (4),

$$Y_t = \mu + \beta t + \delta Y_{t=1} + \theta_1 DU(\square) + \sum \delta_i \Delta Y_{t-i} + \varepsilon_t \tag{4}$$

The ARDL bounds testing equation for the model is written as follows in (5),

$$\begin{aligned}\Delta\text{LNGDPPC}_t = {} & \gamma_0 + \sum_{i=1}^{n} \gamma_{1i}\Delta\text{LNGDPPC}_{t-i} + \sum_{i=0}^{n} \gamma_{2i}\Delta\text{LNPATENT}_{t-i} + \sum_{i=0}^{n} \gamma_{3i}\Delta\text{LNFDI}_{t-i} \\ & + \sum_{i=0}^{n} \gamma_{4i}\text{LNTRADE}_{t-i} + \sum_{i=0}^{n} \gamma_{5i}\text{LNEDU\_EXP}_{t-i} + \theta_1\text{LNGDPPC}_{t-i} + \theta_2\text{LNPATENT}_{t-i} \\ & + \theta_3\text{LNFDI}_{t-i} + \theta_4\text{LNTRADE}_{t-i} + \theta_5\text{LNEDU\_EXP}_{t-i} + \varepsilon_t\end{aligned} \tag{5}$$

where Δ implies the first difference and LNGDPPC, LNPATENT, LNFDI, LNTREADE and LNEDU_EXP representing natural logarithm value of Annual Per Capita GDP, Patent, Foreign Direct Investment, Trade and Education Expenditure, respectively. Furthermore, *t–i* represents the optimum lags determined by the Schwarz information criterion (SIC), γ and θ are the estimated coefficients for short run and long run, respectively.

The long-run and short-run ARDL approach is presented below following (Udeagha and Ngepah 2022b).

The long-run ARDL model to be estimated is given in Eq. (6),

$$\begin{aligned}\Delta\text{LNGDPPC}_t = {} & \beta_0 + \sum_{i=1}^{q} \omega_1\text{LNGDPPC}_{t-i} + \sum_{i=1}^{q} \omega_2\text{LNPATENT}_{t-i} + \sum_{i=1}^{q} \omega_3\text{LNFDI}_{t-i} \\ & + \sum_{i=1}^{q} \omega_4\text{LNTRADE}_{t-i} + \sum_{i=1}^{q} \omega_5\text{LNEDU\_EXP}_{t-i} + \varepsilon_t\end{aligned} \tag{6}$$

In Eq. (6), ω denotes the long-run variance of variables.

For short-run ARDL model with the error correction term used is as follows:

$$\begin{aligned}\Delta\text{LNGDPPC}_t = {} & \beta_0 + \sum_{i=1}^{q} \pi_1\Delta\text{LNGDPPC}_{t-i} + \sum_{i=1}^{q} \pi_2\Delta\text{LNPATENT}_{t-i} + \sum_{i=1}^{q} \pi_3\Delta\text{LNFDI}_{t-i} \\ & + \sum_{i=1}^{q} \pi_4\Delta\text{LNTRADE}_{t-i} + \sum_{i=1}^{q} \pi_5\Delta\text{LNEDU\_EXP}_{t-i} + \text{ECT}_{t-i} + \varepsilon_t\end{aligned} \tag{7}$$

In Eq. (6), π represents the short-run variability of the variables and ECT denotes the error correction term that captures the adjustment speed of disequilibrium.

Simulations using Dynamic ARDL requires to use a stationary dependent variable with strict first-difference assumptions (Sarkodie and Owusu 2020). It follows that cointegration can only occur when the dependent variable is non-stationary at level, *I* (0). Additionally, all sampled independent variables must be either *I* (0) or integrated of order one, *I* (1) with no structural breaks, autocorrelations or heteroskedasticities.

According to Jordan and Philips (2018), the novel Dynamic ARDL simulation equation can be written following (Udeagha and Ngepah 2022a),

$$\begin{aligned}\Delta\text{LNGDPPC}_t = {} & \alpha_0 + \nu_0\text{LNGDPPC}_{t-1} + \varphi_1\Delta\text{PATENT}_t + \rho_1\text{PATENT}_{t-1} + \\ & \varphi_2\Delta\text{FDI}_t + \rho_2\text{FDI}_{t-1} + \varphi_3\Delta\text{TRADE}_t + \rho_3\text{TRADE}_{t-1} + \varphi_4\Delta\text{EDU\_EX}P_t + \\ & \rho_4\text{EDU\_EXP}_{t-1} + \varepsilon_t\end{aligned} \tag{8}$$

A dynamic ARDL error correction algorithm is implemented using 5000 simulations based on a multivariate normal distribution for the parameter vector. ECT is estimated to have a coefficient between − 1 and 0. Explanatory variables are examined using the graphs to determine how they influence the dependent variables. In addition, this study uses diagnostic tests to determine if the model is stable. For serial correlation testing, the Breusch–Godfrey LM test is used; for heteroscedasticity testing, the Breusch–Pagan–Godfrey test and the ARCH test are both used; to ensure that the model is correctly specified, the Ramsey RESET test is used, and for determining if the residuals are normally distributed, the Jarque–Bera test is used. The paper employs two methods for checking structural stability: cumulative sums of recursive residuals (CUSUM) and cumulative sums of squares of recursive residuals (CUSUMSQ). To examine the variables' long-term association with economic growth, we employed the variance decomposition technique to determine the amount of information contributed by each variable to the other variables in the autoregression. Additionally, we used a historical decomposition diagram.

In order to further test the robustness of the model, we reduced it to the cointegrating Nonlinear ARDL (NARDL) by following (Udeagha and Ngepah 2021), with both short- and long-run asymmetry expressions given in Eq. (9),

$$\begin{aligned}\Delta \mathrm{LNGDPPC}_t = {} & \gamma_0 + \sum_{i=1}^{n1} \gamma_{1i} \Delta \mathrm{LNGDPPC}_{t-i} + \sum_{i=0}^{n2} \gamma_{2i} \Delta \mathrm{LNPATENT}_{t-i} + \sum_{i=0}^{n3} \gamma_{3i} \Delta \mathrm{LNFDI}_{t-i} \\ & + \sum_{i=0}^{n4} \gamma_{4i} \Delta \mathrm{LNTRADE}_{t-i} + \sum_{i=0}^{n5} \gamma_{5i} \Delta \mathrm{LNEDU\_EXP}_{t-i} + \wedge_1 \mathrm{LNGDPPC}_{t-1} + \wedge_2 \mathrm{LNPATENT}_{t-1} \\ & + \wedge_3 \mathrm{LNFDI}_{t-1} + \wedge_4 \mathrm{LNTRADE}_{t-1} + \wedge_5 \mathrm{LNEDU\_EXP}_{t-1} + \varepsilon_t \end{aligned} \tag{9}$$

4.2 Data specification

The world development indicator database by World Bank, the Organization for Economic Cooperation and Development's database, the World Intellectual Property Organization's database, and the International Monetary Fund's database are utilized in this research. The primary sources for this study are several publications, book chapters, journals, and newspaper articles. The study analyzed time series data spanning 31 years. Table 1 shows the dependent variable is annual GDP per capita, while the independent variables are Patent Application by Residents and Non-Residents, Foreign Direct Investment Inflows and Outflows, Government Expenditure on Tertiary Education and Trade as a percentage of GDP**.**

Table 1 Symbols and explanations of the variables

Variable	Name	Explanation
GDPPC	Per Capita gross domestic product	Annual GDP Per Capita taken as the dependent variable
PATENT	Patent application filed by residents and non-residents	Annual number of registered patents by residents and non-residents
FDI	Foreign direct investment inflows and outflows	Summation of annual foreign direct investment (FDI) inflows and outflows
TRADE	Trade as a percentage of GDP	Annual trade value
EDU_EXP	Government expenditure on tertiary education	Annual government expenditure on tertiary education

5 Empirical results and discussion

5.1 Summary statistics

Prior to discussing the results, the summary statistics of the variables are examined. The summary statistics of all the dependent and independent variables are illustrated in Table 2, which shows the mean, median, standard deviation, Jarque–Bera and other essential statistical test results. The overview of statistics showing that the average value of economic growth is 4.24. Trade seems to have the largest mean value (34.30) among the variables followed by human capital (13.80), patent (5.599) and FDI (0.735). Besides summarizing the summary statistics, Table 2 illustrates the peak using kurtosis, while Jarque–Bera test statistics determine the normality of our data series. The correlation between the variables is illustrated in Table 2 as well.

5.2 Unit root test estimations

In order to determine the order of integration of variables under analysis, a stationarity test must be conducted before implementing the new dynamic ARDL simulation model. In order to study long-run relationships between variables by cointegrating data, the time series econometrics method requires stationary data. The work relies on Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) unit root tests in Table 3, to verify the asymptotic behavior and order of integration of all variables. In this way, spurious regressions can be resolved. Table 3 shows that in both unit root tests the selected variables are statistically significant at 5% level and are stationary in first difference. The results imply with the conditions of the model chosen for the study. From Zivot and Andrew's structural break unit root test results in Table 4, we acquired evidence that structural breaks persist in empirical literature, affecting the independent variables and economic growth. Time series studies may reveal structural changes that were caused by changes such as economic or political crises. The results of unit root tests will be biased if structural changes occur within the series. Hence, Zivot and Andrew's unit root tests detect structural breaks internally. Current

study is allowing for breaks in both intercept and trend using lag selection via AIC and critical values are found at 1%: −5.57 5%: −5.08 10%: −4.82.

5.3 ARDL bounds testing

ARDL bounds test examine the long-run association among the study variables indicated in Table 5. The ARDL is statistically significant in the long run because the probability is less than 5%. In the long run, ARDL explains that the bound test's F statistic value (6.196) is bigger than the lower bound (3.47) and upper bound (4.57) at 5%, showing that dependent and independent variables are interconnected in the long run. In each case, SIC criteria are used to determine the optimal lag length and reject the null hypothesis of no cointegration. Therefore, the model passed the cointegration test with the correct lag selection, which reduced residual correlation and also minimized endogeneity.

5.4 Estimating dynamic ARDL simulations

The dynamic ARDL model by Jordan and Philips (2018) assists in estimating, simulating, and forecasting real regressor changes and their effects on degeneration. Simulations using Dynamic ARDL requires to use a stationary dependent variable with strict first-difference assumptions (Sarkodie and Owusu 2020). It follows that cointegration can only occur when the dependent variable is non-stationary at level,

Table 2 Summary statistics and correlation statistics

	LNGDPPC	LNPATENT	LNFDI	LNTRADE	LNEDU_EXP
Mean	4.244764	5.599494	0.735555	34.30567	13.80020
Median	4.390980	5.723585	0.669200	35.30400	11.13890
Maximum	7.412894	5.908083	2.100026	48.11092	33.27739
Minimum	1.690416	4.672829	0.009479	19.93401	4.737890
Std. Dev	1.615162	0.333264	0.568567	7.891131	8.356598
Skewness	0.221593	−1.474209	0.474224	0.053778	1.656414
Kurtosis	1.957042	3.990982	2.390809	1.944213	4.542712
Jarque–Bera	1.551712	11.69088	1.535388	1.360891	16.13704
Probability	0.460310	0.002893	0.464082	0.506391	0.000313
Sum	123.0982	162.3853	21.33111	994.8644	400.2058
Sum Sq. Dev	73.04494	3.109820	9.051519	1743.559	1955.317
Observations	31	31	31	31	31
Correlation matrix					
LNGDPPC	1.000000				
LNPATENT	0.683209	1.000000			
LNFDI	0.581486	0.632906	1.000000		
LNTRADE	0.716672	0.709905	0.877531	1.000000	
LNEDU_EXP	0.584451	0.442422	0.412465	0.435140	1.000000

I (0). Additionally, all sampled independent variables must be either at levels *I* (0) or integrated of order one, *I* (1) with no structural breaks, autocorrelations or heteroskedasticities. Our results successfully met the following criteria. Through the Error Correction Term (ETC), short-run adjustments can be balanced with long-run equilibrium by using the ECT coefficient and accompanying *p* value thus indicating model stability. ECT indicates the error correction term that measures the speed of adjustment. There is a statistically significant negative correlation between ECT and the results examined. The ECT term indicates that 75% disequilibrium is corrected in the long run. The *R*-squared value indicates that 89% variations in regressed are due to the utilized regressors of this study. The estimated *p* value of *F*-statistics indicates that the model is fit. The dynamic ARDL error correction procedure applied in this paper used 5000 vector simulations of standard multivariate circulated variables. The resultant diagrams actively analyze the regressor's actual shift and effect on the regressed. With dynamic ARDL simulations, the predictions of actual changes in the regressors are automatically plotted along with the impact on the regressed while the other regressors are held constant. The dynamic ARDL simulations model results in short and long run are reported in Table 6.

According to Table 6, technological innovation and human capital have a positive long-term impact on economic growth, whereas foreign direct investment and trade have a negative long-term effect. In particular, an increase of 1% in LNPATENT and LNEDU_EXP led to an increase of 3.64% and 0.14% in LNGDPPC, respectively. LNGDPPC is reduced by 0.08% and 0.01%, respectively, if LNFDI and LNTRADE are increased by 1%. In the long run, the economic growth decrease is relatively modest, as demonstrated by the negative long run results. As a result of the high R^2 value of 90%, the overall model is robust. ECT is found statistical significance and negative sign, this estimate confirms that there is a steady long-run relationship between the variables under analysis. An estimate of the ECT at −0.75 suggests that in the long run, 75% of the disequilibrium will be corrected. *F*-statistics suggest that the model is well fitting based on the estimated *p* value. In the short run, 1% increase in economic growth causes increases by 1.42%, 0.10% and 0.01% in patent, trade and education expenditure, respectively. Only FDI shows a 0.03% decrease with an increase in economic growth. A determination coefficient determined in Table 6 indicates that 90% of the changes in economic growth can be attributed to the independent variables included in the model, including patents filed by residents and non-residents, foreign direct investment inflows and outflows, trade openness, and human capital indicators. Other than that, the changes are a result of random factors.

For technological innovation, from our research it is evident that technological innovation contributes positively to economic growth, however, the long run effects are positive but not statistically significant, whereas the short-run effects are both positive and statistically significant. In conventional economics, the latent period of technological development has often been ignored and viewed as black box in economic scenarios of technological change (Mohamed et al. 2022). From the initial invention, through core technology development and new product development, to the development of market strategies, this is a first attempt at a comprehensive description of the innovation paradigm.

Table 3 Augmented Dickey–Fuller (ADF) and Phillips–Perron (PP) Unit root tests results Source: Authors' calculations

Variables	Augmented Dickey–Fuller				Phillips–Perron			
	Levels		First difference		Levels		First difference	
	No trend	Trend	No trend	Trend	No trend	Trend	No trend	Trend
LNGDPPC	0.6067	−2.6077	−7.4522***	−7.8106***	1.1415	−4.1731**	−7.3436***	−15.0548***
LNPATENT	0.4861	−2.7096	−7.6584***	−8.1258***	1.0901	−2.6416	−7.9555***	−10.6262***
LNFDI	−0.9139	−1.6302	−6.4665***	−6.5004***	−0.7707	−1.6188	−6.4665***	−6.7287***
LNTRADE	0.6200	−1.4714	−4.9270***	−5.1797***	0.5936	−1.4714	−4.9281***	−5.3322***
LNEDU_EXP	−0.6992	−1.7248	−8.6018***	−3.2878*	−1.0360	−3.6631**	−8.6695***	−8.2662***

*, ** and ***statistical significance at 10%, 5% and 1% levels, respectively

Table 4 Zivot &Andrew's stationarity test for structural break estimations Source: Authors' calculations

Variables	Level			First difference		
	t-statistics	Break year	Outcome	*t*-statistics	Break year	Outcome
LNGDPPC	−3.659	2005	Unit root	−6.710***	2008	Stationary
LNPATENT	−5.676***	2000	Stationary	−8.433***	2002	Stationary
LNFDI	−5.410**	2013	Stationary	−7.544***	2014	Stationary
LNTRADE	−4.397	2011	Unit root	−6.007***	2005	Stationary
LNEDU_EXP	−4.763	2014	Unit root	−9.765***	2014	Stationary

*, ** and ***statistical significance at 10%, 5% and 1% levels, respectively

Table 5 ARDL Bounds testing estimations Source: Authors' calculations

Test Statistics	Value	k	H_0 No level relationship		H_1 Relationship exists	
F-statistics	6.196660***	4				
t- statistics	−4.530396**					
Significance	*F*-statistics		*t*-statistics		*p* value F	
	I (0)	*I* (1)	*I* (0)	*I* (1)	*I* (0)	*I* (1)
10%	3.03	4.06	−3.13	−4.04	0.0000***	0.0000***
5%	3.47	4.57	−3.41	−4.36	*p* value *t*	
1%	4.4	5.72	−3.96	−4.96	0.0005***	0.0012***

*, ** and ***statistical significance at 10%, 5% and 1% levels, respectively

It is well established that technological advancements are essential to reducing the gap between developed and developing countries in economic development and achieving the so-called catch-up growth for developed countries. It is also in line with (Mohamed et al. 2021) since their estimation of the rate of growth of the Egyptian economy per capita gross domestic product has a complementary relationship with the rate of growth of the Egyptian economy's technological innovation. According to Law et al. (2020), insufficient innovation technology flows over the long term negatively affect Malaysia's innovation capacity. A study by Fan et al. (2018) found that technological innovation in the short run can positively and significantly influence the industrial growth of Bangladesh, but that it has a negative impact in the long run. Bangladesh's economic growth can be positively impacted by financial institutional innovation, according to a study conducted by Qamruzzaman (2017). As part of the formulation of economic policies, governments and policymakers need to take into account the interrelationship between institutional innovation and economic growth. A robust financial system is created by promoting financial innovation between banks, non-banking institutions, and capital markets.

For foreign direct investment, a negative, insignificant outcome was found in our study in both long-run and short-run estimates. Different economists interpret the relationship between foreign direct investment and economic growth differently. Some consider economic growth to be an important determinant for foreign direct

Table 6 Estimations of dynamic ARDL simulation analysis
Source: Authors' calculations

Variables	Coefficient	St. Error	*t* Value	Prob.
Cons	−6.829111**	2.524519	−2.705114	0.0129
Long-run coefficients				
LNGDPPC	−0.389814**	0.162558	−2.397995	0.0254
LNPATENT	3.637324	2.191874	1.659459	0.1112
LNFDI	−0.081818	1.263514	−0.064754	0.9490
LNTRADE	−0.011742	0.125969	−0.093213	0.9266
LNEDU_EXP	0.140088	0.058521	2.393803	0.0256
Short-run coefficients				
ΔLNGDPPC	0.610186***	0.162558	3.753640	0.0011
ΔLNPATENT	1.417881**	0.544616	2.603453	0.0162
ΔLNFDI	−0.031894	0.495791	−0.064329	0.9493
ΔLNTRADE	0.104728*	0.054280	1.929396	0.0667
ΔLNEDU_EXP	0.019499	0.020289	0.961060	0.3470
ECT (−1)	−0.751001	0.124108	−6.051167	0.0000
R-Squared		0.899195		
Adj. *R*-Squared		0.860793		
N		31		
Prob (*F*-statistic)		0.0000***		
Simulations		5000		

*, ** and ***statistical significance at 10%, 5% and 1% levels, respectively

investment. Some research findings, however, illustrate the negative effect foreign direct investment inflows may have on efforts to innovate and the current account deficit when viewed from the perspective of the negative position foreign direct investment can play in achieving economic growth. Further, it needs to be noted that large entry of foreign direct investment into the country leads to high economic growth, while the opposite is also true, and several relationships are cited to explain the relationship between foreign direct investment and economic growth (Montresor and Vezzani 2021). In order to reduce inflation and boost GDP growth rates, it is appropriate to pay attention to raising investment rates. Investment directly affects the supply of goods and services (thus reducing inflation) (Xu et al. 2022). A major factor in determining the relationship between foreign direct investment and economic growth is technological innovation found in our empirical research incorporates with Dutta et al. (2021), Mohamed et al. (2021). As our research results long-run and short-run estimates of FDI shows insignificance and negative correlation with economic growth, and the results are in line with Udeagha and Ngepah (2022b), as they highlighted in low-income countries foreign direct investment does not have a positive impact on these economies. Consequently, these researchers also contend, FDI's negative outcomes are affecting economic growth negatively. Such investments also force companies to limit growth and competition by leveraging their market position. The viewpoint presented here sees foreign direct investment as a wasteful distribution of capital caused by government interference in the

host country (Mohamed et al. 2021). In a similar manner, the introduction of foreign direct investment in a state when it is not necessarily beneficial to local businesses and associated skills, but they may instead seem to suffer a dramatic decline in productivity as a result. There is a significant disagreement among economists about the nature of the outcome, as evidenced by various economic literature. A certain level of technological innovation may explain this correlation by FDI resulting in strong economic development. Because foreign direct investment brings with it new and modern technology, which may not be commercially available in host countries (Uddin 2022). In contrast, host countries are able to increase their production thanks to foreign direct investment, particularly since innovative companies do not wish to sell their technologies to local businesses directly (Mohamed et al. 2022). A number of global companies have expanded their business in Bangladesh in recent years due to political stability and a wealth of infrastructure development. Uber, Food Panda, Alibaba, and Amazon are among the global companies that have expanded their businesses. An official source with the Bangladesh Bank states that Bangladesh has received an average of $3.61 billion in foreign direct investment per year for the past decade, with FDI totaling $3.89 billion alone in 2019. FDI in the power and energy sector amounted to the highest amount in 2019 (Byron and Barua 2022).

For trade openness, we found there is a significant positive correlation between short-run trade openness and economic growth. The results can be compared with the research of Kong et al. (2021), Qamruzzaman and Jianguo (2017), Udeagha and Ngepah (2021) during study these authors demonstrated that trade openness had a significant positive impact on economic growth and also with FDI which supports the idea that trade barriers should be eliminated in order to promote free movement of capital. In Udeagha and Ngepah (2022a) study, trade share is captured as well as trade size relative to world trade using an innovative measure of trade openness for South Africa, a country with highly differentiated trade openness, and TI-based measures of trade openness were overwhelmingly used. Similarly, Hasan (2021) examined the relationship between Bangladesh's economic growth and trade openness from 1992 to 2019. Based on both cointegration and Granger causality analyses, the author demonstrated that trade openness has positive and significant effects on Bangladeshi economic growth over the long run, but not over the short run. In their study, Omoke and Opuala Charles (2021) looked at total trade, import trade, and export trade as indicators of trade openness. An ARDL bounds test is used to examine cointegration among the variables and results show that there is a significant long-run relationship between the variables. The impact of export trade on economic growth is significant and positive, while the impact of import trade is significant and negative. As institutional quality improves, so does the negative long-run impact of import trade on economic growth in Nigeria. Based on the analysis of Duodu and Baidoo (2020) on Ghana's economic growth between 1984 and 2018, the authors also considered the importance of institutions in contributing to economic growth. It is evident from the results of the autoregressive distributed lag model (ARDL) that both trade openness and quality of institutions play an important role in economic growth, both in the long run and in the short term. Economic growth, however, does not appear to be affected by the interplay between trade openness and quality of institutions. It has been shown using a VAR framework that trade

openness at a disaggregated level is closely related to investment and economic growth in BRICS countries. A study conducted by Burange et al. (2019) indicates gross capital formation tends to increase GDP per capita over the short term, while merchandise exports negatively impact GDP per capita growth. Additionally, service imports have a positive impact on GDP per capita. In our empirical research, the long run trade openness illustrates a negative and non-significant result which implies with the studies of Zahonogo (2016) where a dynamic growth model was applied based on data from 42 SSA countries from 1980 to 2012 to examine how trade openness affects economic growth in developing countries, with a focus on sub-Saharan Africa (SSA). This technique is appropriate for drawing conclusions from dynamic heterogeneous panels when considering long-run equilibrium relations, as it considers dynamic heterogeneous panels from the perspective of long-run equilibrium relations. Economic openness contributes to technological advancement and productivity improvement by improving the transfer of new technologies, and that these benefits are correlated with trade openness. In the short and long term, trade reduces resource misallocation and facilitates the transfer of technological developments, while it creates economic incentives that boost productivity through two dynamics (Nusair and Al-Khasawneh 2022). Studies using differential proxies for trade openness and relying on different methodologies are contributing to the inconclusive results in the literature. In light of misspecification problems as well as the diversity of openness indices used, the evidence for growth enhancements by trade is mixed. As a result of a lack of a well-functioning financial system, less developed countries may not be able to fully benefit from trade openness and economic growth will be affected. Having an open trade policy is not an automatic benefit. Trade openness must be accompanied by policies aimed at improving macroeconomic stability. There is a direct correlation between the level of trade liberalization and the growth of the economy. Several empirical studies have demonstrated a two-way causality relationship between trade and growth, with countries with greater trade likely to have higher incomes. In addition, countries with higher incomes may have better access to infrastructure conducive to trade, or they may have more resources to overcome information search costs associated with trade, or they may demand more goods that are traded (Mohamed et al. 2022).

For human capital, our results indicate that there is a positive correlation between human capital and economic growth. There is still much work to be done in order to maintain Bangladesh's economic stability even as it grows rapidly at the moment. Even though Bangladesh has a good literacy rate, it could not resist having 5.3% unemployment rate relative to the population. Pre-pandemic, Bangladesh had a 4.22 percent unemployment rate, but as a result of layoffs in most organizations during the pandemic, the rate has increased slightly. In addition, thousands of Bangladeshis migrate each year to study and work in higher education and employment. Through investing in education, an organization can develop highly productive, skilled, and knowledgeable resource endowments, which in turn will help other natural endowments be best utilized and exploited in a way that will bring about the much-needed transformation of a country (Mercy 2019). The positive correlation between human capital and economic growth both in the long run and the short run revealed in our study has shown similar results with Jesusetemi Oluwafemi et al. (2018), Krokeyi

and Niyekpemi (2022), Qamruzzaman and Jianguo (2017), Wu and Liu (2021), Zhang et al. (2021), etc. Based on evidence from 1981 to 2018, Krokeyi and Niyekpemi (2022) examine the impact of human capital development on economic growth in Nigeria. In this study, the Ordinary Least Square (OLS) technique was employed and the focus was on the effect of government expenditure on education, health, and economic growth in Nigeria, as well as the causal relationship between human capital variables and economic growth. There is statistical evidence that government expenditures on education are statistically significant and have a significant impact on the real economy. Similarly, another article by Wu and Liu (2021) collects panel data from different regions of China during the period 2006 to 2019 and then develops a system of indices to measure higher education development, technological innovation levels, and industrial structure upgrades. It was found that there is a significant positive evidence of spatial spillover effects of higher education and technological innovation on industrial structure upgrades when using the spatial Dubin model and the paper is occupied in learning the spatial effects of higher education and technological innovation. Nigerian human capital and economic growth nexus in between 1981 and 2017 are empirically examined in the study of Keji (2021). The cause is poor policy impact across the key sectors of the economy, such as education and health, which would have transformed productivity into economic growth in Nigeria. Economic growth in Nigeria has been significantly affected by the estimated coefficients of human capital over the long run, as shown by the results of the study. Based on the analysis of Jesusetemi Oluwafemi et al. (2018), it is also clear that economic growth is positively correlated with human capital development. Nigeria's economic growth has been attributed to the high level of human capital development which has increased the utilization of resources. Siddiqui and Rehman (2017) examines the HC-growth nexus across nine Asian countries using a disaggregated regional perspective. To attain 'informationally' efficient estimates of the impact of HC on the stock and levels of GDP, the methodology uses an Empirical Bayesian approach, which addresses not only the heterogeneity issue but also the common structural priors of regional countries. Economic growth in Asian regions can be explained by different measures of human capital. East Asia's economic growth fluctuations were largely explained by primary and secondary education, while South Asia's economic growth was largely explained by vocational and tertiary education. Several regions showed a positive impact on economic growth from government education spending. It is established by the results that different countries have different growth rates because of their differing educational progressions. Due to a variety of factors, Bangladesh has had a difficult time growing and developing since the nation became independent, one of which is an inadequate focus on human capital development. Additionally, political variability often leads to recurrent fluctuations in educational policies, and the government intentionally underfunds the education sector. It is important to raise the level of education system so that it is able to achieve sound human capital development, and to provide adequate budgetary allocations to enhance the development of human resources and their relevant components. Due to Bangladesh's frequent structural changes and limited technological advancements, these findings are surprising, and it is important to sustain this positive trend to ensure our country's continued advancement.

In dynamic ARDL simulations, the forecasts of actual regressor changes and their impacts on the dependent variable are automatically plotted while other explanatory variables are kept constant. It is forecasted that Bangladesh's economic growth will be influenced by explanatory variables such as technological innovation, foreign direct investment, human capital and trade openness by 1%. An impulse response plot is shown in Figs. 2 and 3, depicting the relationship between technological innovation and economic growth. When technological innovation increases by 1%, it is assumed to be beneficial to economic growth in the short run and in the long run. However, when technological innovation decreases by 1%, it indicates a negative effect on economic growth. However, an increase of 1% in innovation has a greater impact than a decrease of 1%. Thus, Bangladesh's economy benefits from technological innovation both in the short run as well as in the long run, but suffers from a decline in technological innovation. The graph in Figs. 2 and 3 also shows the actual change in the patent and its influence on the GDP per capita. The dots indicate the average prediction value, while the dark blue to light blue line indicates 75, 90, and 95% confidence intervals. In this study, the shock to economic growth occurs at time $t = 10$ and in 1% variation. These effects are generated by the author estimating the model formula, extracting the estimated coefficients from the model, generating several simulated coefficients from a multivariate normal distribution with mean and variance determined by the estimated coefficients and variance–covariance from the model, and using them to predict the dependent variable's values. It monitors the predicted values' response to simulated shifts in the independent variables.

Figures 4 and 5 indicate the impulse response plot for checking the relationship between foreign direct investment and economic growth. Contrary to our previous finding, the FDI and economic growth impulse response graph indicates that 1% increase positively affects economic growth while a 1% decrease in FDI indicates that it negatively impacts economic growth both in the long run and short run. The dots indicate average prediction value while the dark blue to light blue line indicates 75, 90, and 95% confidence interval, respectively.

A relationship between trade openness and economic growth can be seen in Figs. 6 and 7. These plots illustrate how trade openness affects GDP per capita and the progression of the dependent and independent variables. Trade increases have negative effects on long-term economic growth, while trade decreases have positive effects on short-term GDP per capita. More specifically, short-term economic growth is negatively affected by an increase in trade, while a decrease in trade is positively impacted by a decrease in trade both short term and long term. The dots indicate the average prediction value, while the dark blue to light blue line indicates 75, 90, and 95% confidence intervals.

Figures 8 and 9 show the impulse response plot of education expenditure and economic growth. It has been shown that increasing education expenditures by 1% can have positive effects on both short- and long-term economic growth, and that reducing education expenses by 1% can also increase GDP per capita. The graph in Figs. 8 and 9 shows the actual change in the human capital and its influence on the

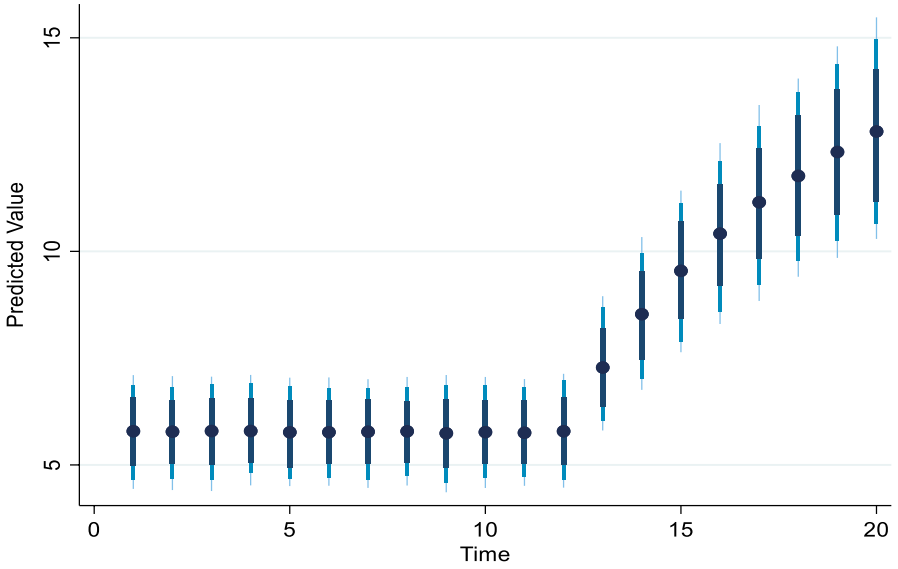

Fig. 2 Technological innovation and GDPPC impulse response plots

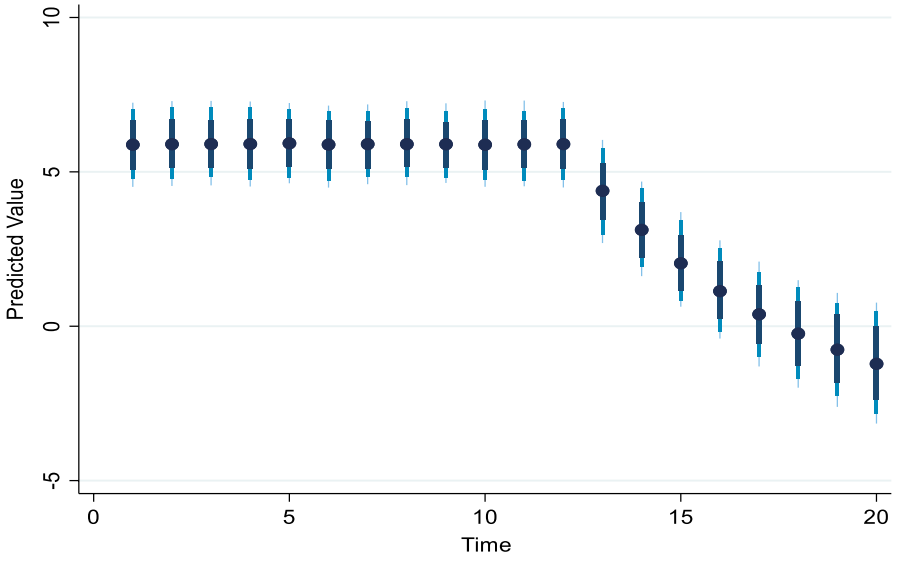

Fig. 3 Technological innovation and GDPPC impulse response plots

GDP per capita. The dots indicate the average prediction value, while the dark blue to light blue line indicates 75, 90, and 95% confidence intervals.

5.5 Residual diagnostics statistics

Based on the empirical results of diagnostic statistics tests in Table 7, we ensured that our chosen model is reliable and consistent. From the observed results, it appears that the model used is well fitted, as all diagnostic tests have been successfully completed. The Breusch–Godfrey Lagrange multiplier (LM) was used to test the serial correlation. The Breusch–Pagan–Godfrey test was used to check for heteroscedasticity, and the Jarque–Bera test was used to check for residual normality. As confirmed by the Breusch–Godfrey LM test, the model doesn't suffer from serial correlation or autocorrelation problems. Model misspecification is not found with the Ramsey RESET test. The Breusch, Pagan–Godfrey, and ARCH tests are both employed to determine whether the model exhibits heteroscedasticity, and the results suggest that it does not have any problems. Jarque–Bera tests indicate that the residuals of the model follow a normal distribution.

5.6 Stability tests

To further validate the robustness and consistency of the model, the cumulative sum of residuals (CUSUM) and cumulative sum of squares of residuals (CUSUMSQ) were applied to the structural stability evaluation of the model. A model's

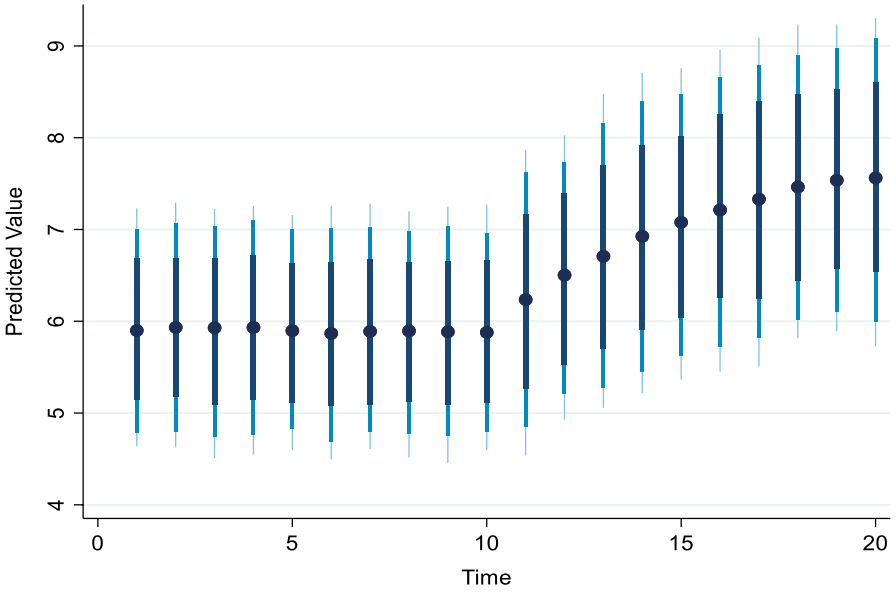

Fig. 4 Foreign Direct Investment and GDPPC impulse response plots

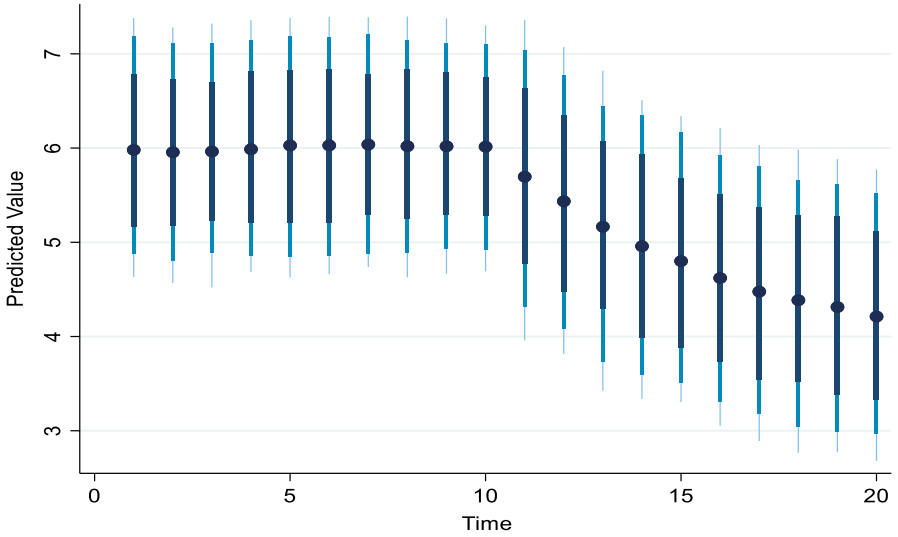

Fig. 5 Foreign direct investment and GDPPC impulse response plots

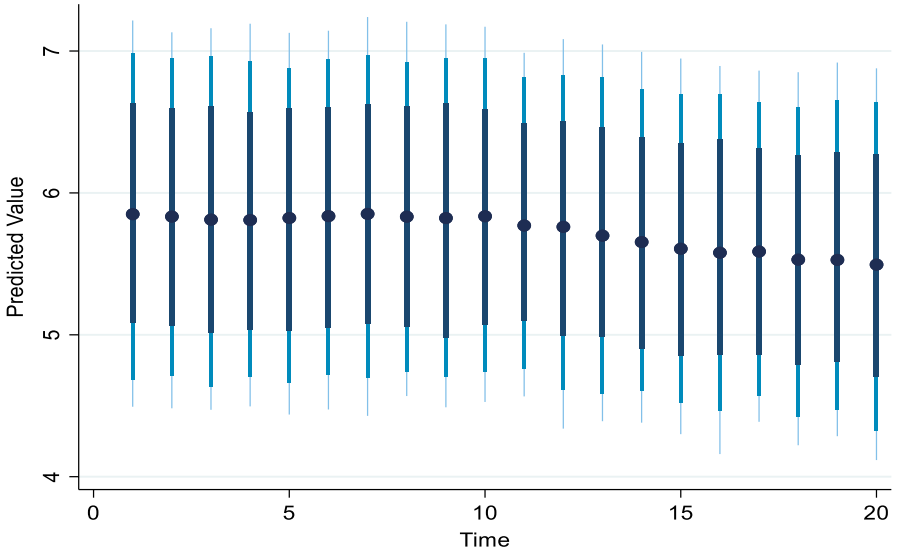

Fig. 6 Trade openness and GDPPC impulse response plots

parameters are considered stable over time if plots are within a critical bound level of 5% and parameters remain stable. Figure 10 presents a visual representation of CUSUM and CUSUMSQ. Since CUSUM and CUSUMSQ are within the bounds at a 5% level, hence the parameters of the model are stable.

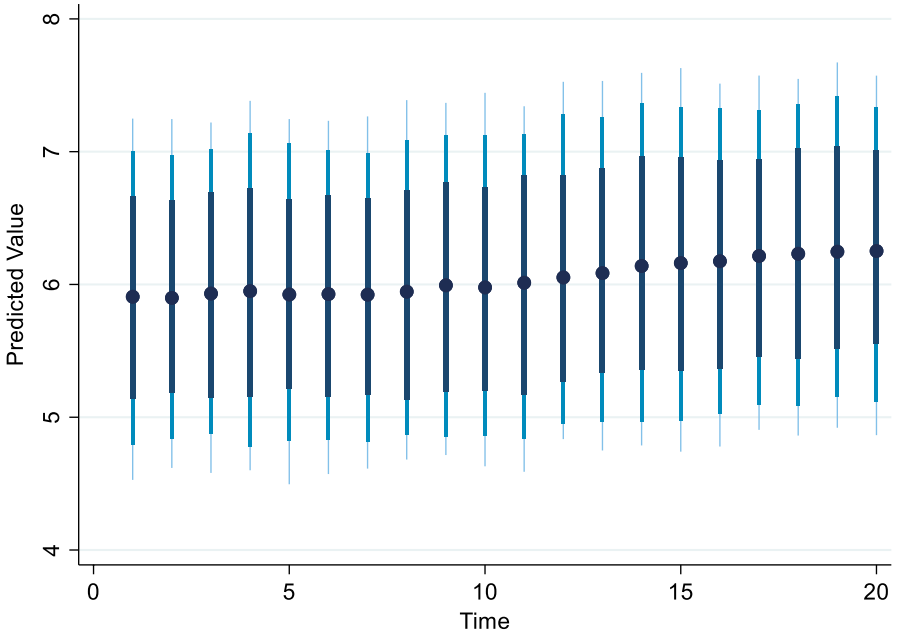

Fig. 7 Trade openness and GDPPC impulse response plots

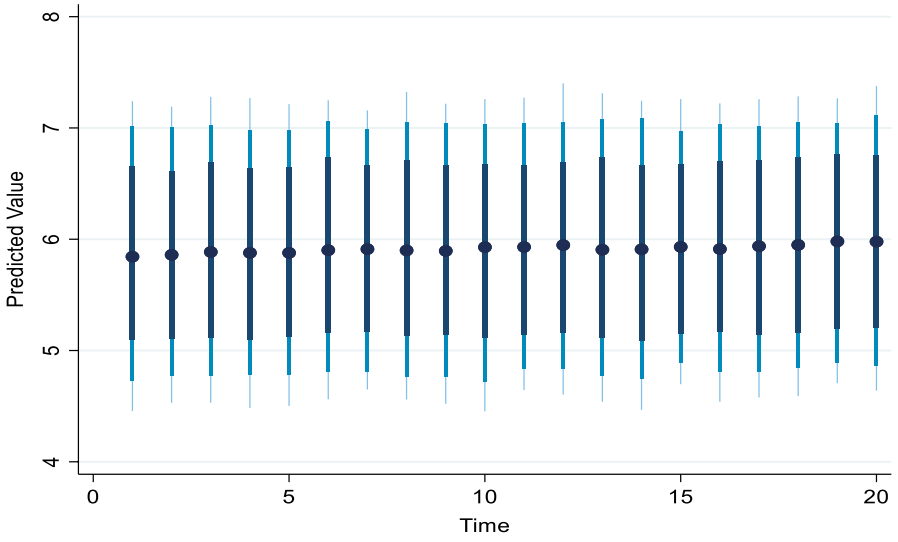

Fig. 8 Human Capital and GDPPC impulse response plots

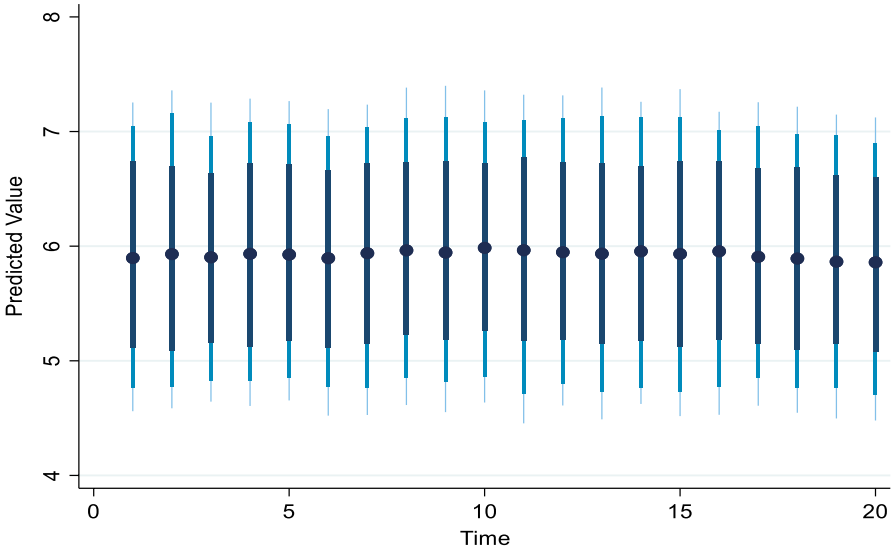

Fig. 9 Human capital and GDPPC impulse response plots

5.7 Robustness check

In order to authenticate the research and also answer the question raised at the beginning of our study, whether Bangladesh's economic growth and policymaking are symmetrical or asymmetrical in light of these innovation and growth factors, an alternative nonlinear estimation approach, the NARDL, is employed to check the robustness of the long-run and short-run estimated parameters (Table 8).

Table 7 Residual diagnostics estimations

Values	Results
R^2	0.8991
Adjusted *R*-squared	0.8607
F-statistic	16.4874, Prob (*F*-statistic: 0.0000)
Durbin–Watson stat	1.8462 (no autocorrelation)
Autocorrelation (*Q*-stat)	0.0065 (Prob = 0.936)
Breusch–Godfrey LM test	*F*-stat: 0.5423, No problem of serial correlations
Breusch–Pagan–Godfrey Test	*p* value = 0.3529, No problem of heteroscedasticity
ARCH Heteroskedasticity test	*p* value = 0.3116, No problem of heteroscedasticity
Normality	Residuals are normally distributed
Ramsey RESET test	*t*-stat (1.5711), *F*-stat (2.4684), Model is specified correctly
Multi-collinearity	No
Stability test: CUSUM @5%	Significant
Stability test: CUSUMSQ @5%	Significant

Source: Authors' calculations

According to our asymmetrical approach in this research, technological innovation has a negative and nonsignificant long-term impact on economic growth when it is accompanied by a positive shock and a positive and significant impact when it is accompanied by a negative shock. The short-run effect of technological innovation on economic growth is positive and statistically significant. This results shows similarity with our dynamic ARDL simulations study estimations. When economic growth is stimulated by positive shocks, foreign direct investment has both a positive and a statistically significant impact on it. When economic growth is stimulated by negative shocks, it has both a negative and an insignificant impact. When positive shocks are applied, trade openness has a positive and statistically significant effect on economic growth, whereas when negative shocks are applied, it has both negative and an insignificant impact. Human capital impacts economic growth positively and statistically significantly in the long run when positive shocks are present, but negatively in the short run when negative shocks are present. There is statistical significance to the majority of variables, although their magnitudes may vary slightly between them. It appears that these macroeconomic covariables have an asymmetric effect and are more pronounced in the short run than in the long run. These evidence leads us to conclude that the results obtained by the NARDL model are robust, consistent, and do not differ significantly from the results obtained by the dynamic ARDL simulation framework.

5.8 Variance decomposition

A variance decomposition test and a historical decomposition test were performed as part of our study to enhance it further as it is useful for evaluating how external shocks are channeled through a system. This feature plots the decomposition of forecast variances as line graphs that demonstrate the relative importance of each innovation. Decomposition is a tool used primarily for analyzing and understanding historical time series, but can also be used to forecast. It consists of breaking them down into different components, each with its own properties and behavior. The prediction error measures the unpredicted variable fraction induced by shocks caused

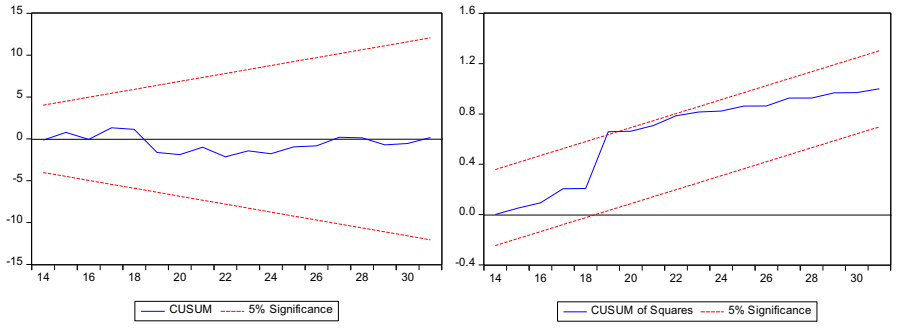

Fig. 10 CUSUM and CUSUM of squares

Table 8 Estimations of Nonlinear ARDL for robustness check Source: Authors' calculations

Variables	Coefficient	St. error	*t* value	Prob.
Cons	2.712590***	0.395354	6.861164	0.0000
Long-run coefficients				
LNGDPPC	−0.878702***	0.123490	−7.115589	0.0000
LNPATENT_POS	−0.730158	0.806036	−0.905863	0.3777
LNPATENT_NEG	6.677725**	1.221811	5.465432	0.0000
LNFDI_POS	0.264583**	0.115050	2.299729	0.0344
LNFDI_NEG	−0.227798	0.260170	−0.875573	0.3935
LNTRADE_POS	1.814859**	0.776497	2.337240	0.0319
LNTRADE_NEG	−0.754731	1.908197	−0.395520	0.6974
LNEDU_EXP_POS	0.991134***	0.333619	2.970859	0.0086
LNEDU_EXP_NEG	−1.122817***	0.354165	−3.170320	0.0056
Short-run coefficients				
ΔLNPATENT_NEG	3.170903***	1.018953	3.111924	0.0063
ΔLNTRADE_NEG	12.85668***	3.310507	3.883600	0.0012
ECT-CointEq (−1)	−0.763311***	0.060471	−12.62269	0.0000
R-squared	0.851740			
Adjusted *R*-squared	0.840335			
F-statistic	13.77040	5% Significance	*I* (0) 2.11 *I* (1) 3.15	

*, ** and ***statistical significance at 10%, 5% and 1% levels, respectively

by other variables in each variable. We used the variance decomposition analysis by applying the Cholesky decomposition approach to assess the importance of one variable's causal effect on another and evaluate how each variable is responded to changes in other variables. Analyzing the relative significance of each innovation to endogenous variables involves decomposing the fluctuations and the reasons for each variable. The result of variance decomposition of variables is shown in Fig. 11.

5.9 Historical decomposition

The historical decomposition shown in Fig. 12 within vector autoregression is a standard that interprets historical fluctuations in the modeled time series in terms of the identified structural shocks.

We can now summarize our discussion by emphasizing on how technology innovation, foreign direct investment, trade openness, and human capital are related to economic growth of Bangladesh based on the findings of the study. This paper attempts to resolve this debate by using three different methodologies. In order to compare the results obtained from different experimental methodologies, we estimated linear, nonlinear and dynamic simulations techniques simultaneously. The models differ in their statistical capabilities depending on the adaptation variables included in the models. Here are some of the key results of this study: (1) According

to the symmetric ARDL model, technological innovation has a positive but non-significant (positive and significant) long-term (short term) effect on economic growth; (2) Foreign direct investment has a negative and non-significant impact on economic growth both in the long and short term; (3) the presence of a negative and non-significant and strong positive and significant effect of trade openness on economic growth in the long and short term, respectively; and (4) the presence of a positive and significant (positive and non-significant) effect of the human capital on the rate of economic growth in the long term (short term). Technological innovation, foreign direct investment, and human capital when examined using a dynamic simulation testing method and showed that with an increase in these variables, the economy grows, while with a decrease in the value of the variable, the economy suffers. Only trade openness demonstrates that trade increases and the economy declines. In the dynamic simulation method, we predicted a 1% increase and decrease in the independent variables, i.e., patent, foreign direct investment, trade, and education expenditure, its impact on the economic growth of Bangladesh. Considering the future time path of study variables, estimates of long-run and short-run coefficients provide important policy implications pertaining to the topic at hand. Figures 2, 3, 4, 5, 6, 7, 8, and 9 show an impulse response plot that indicates economic growth

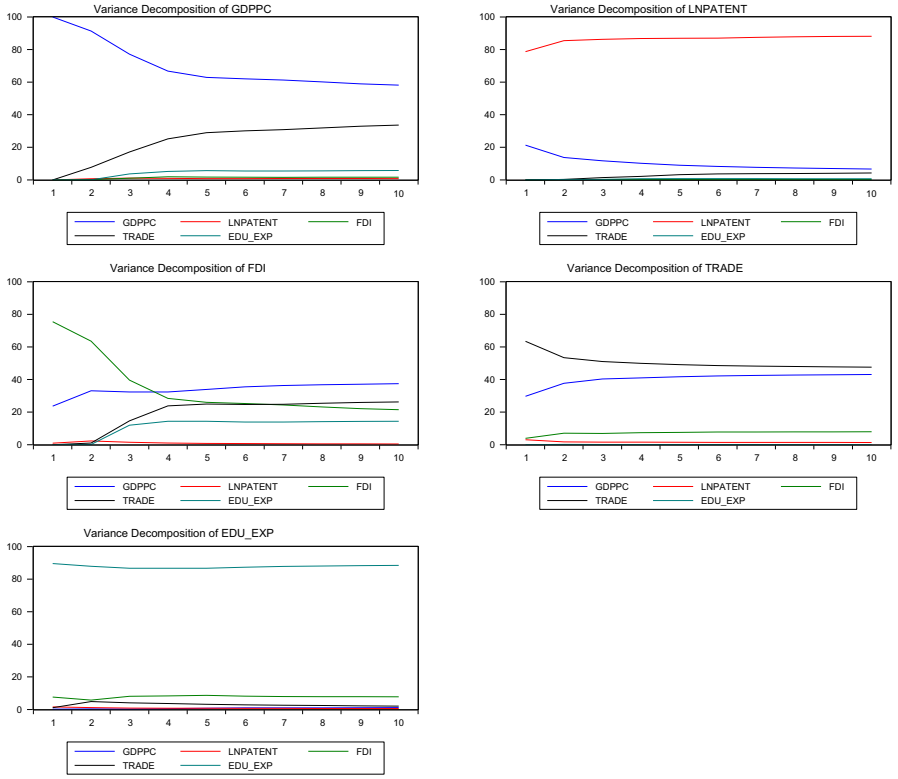

Fig. 11 Variance decomposition

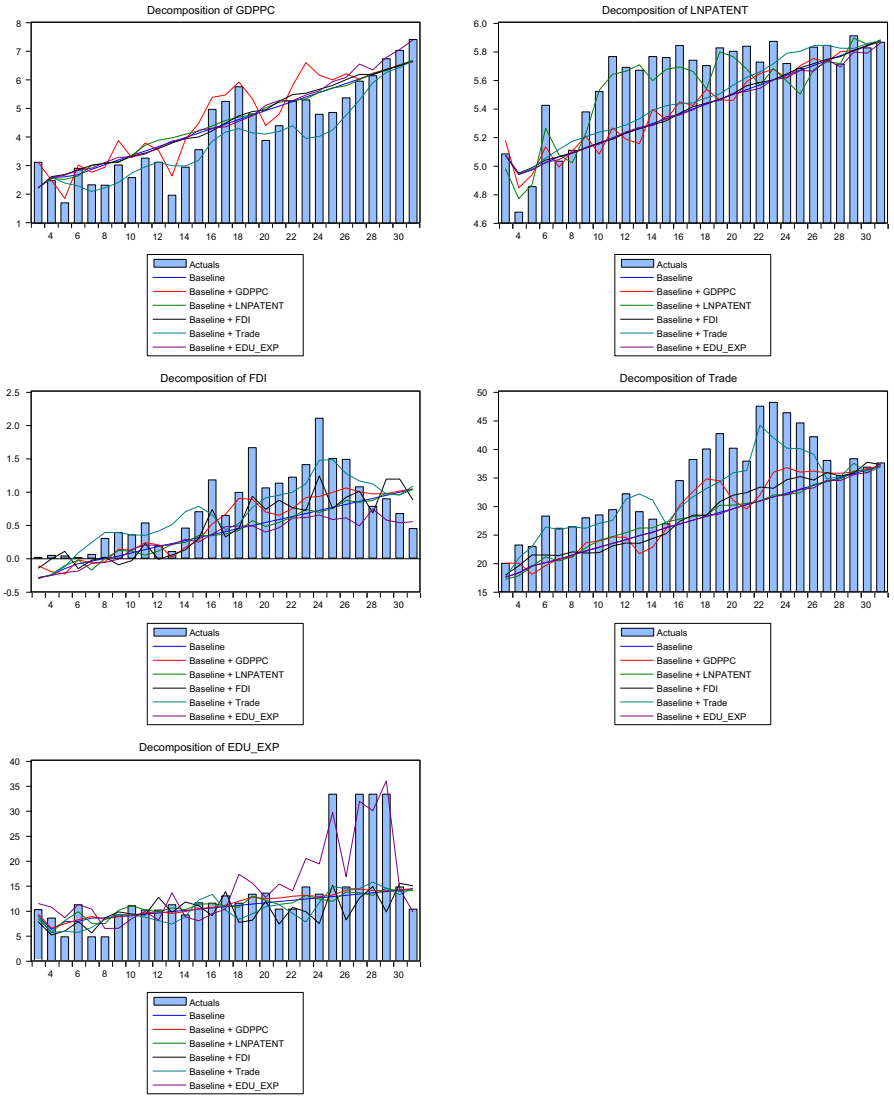

Fig. 12 Historical decomposition

with independent variables. The graphs show the actual change in each independent variable and its influence on economic growth. The typical positive changes show an upward trend in the plot, and the negatives show a downward trend. In this study, only trade shows a different trend. While the positively shocked trade trend is downward, in negative shock, its trend is upward. When using dynamic ARDL, variations in the determinants can be obtained by changing the number of simulations. This should smooth out period-to-period fluctuations in the confidence intervals but at the expense of increased computing time. The critical aspect of ARDL modeling of

post-estimation diagnostics is ensuring that any ARDL estimation produces white noise residuals. To this end, the robustness checking tools, proposed by Pesaran M. and Pesaran B. (1997) the cumulative sum of recursive residuals (CUSUM), and cumulative sum of squares of recursive residual (CUSUMSQ) are used. Figure 10 displays the model trend over time. Further validation of the robustness is provided by an asymmetrical ARDL approach. For robustness checking, the asymmetrical approach shares similarities with both linear and dynamic approaches in the short run. Our discussion concluded by showing that the variables studied are responsible for a significant rise in economic development (for example, R^2 values for both symmetric and asymmetric regressions were found to be 90% and 85%, respectively, in analysis) which revealed that the effect and relations of the dependent variables the growth of Bangladesh economy.

6 Conclusions and policy implications

6.1 Conclusions

Economic variations are mainly caused by a combination of technological, financial, business, and human factors. As a result of developments of these factors, the economy of the country is experiencing rapid growth, which makes individual resources more scarce and significant shifts in economic activity possible. There have been challenges found in global outlook for the economy worldwide recently, along with an increasing threat of a global recession due to war and pandemic. This requires developing countries to encourage positive thinking, innovative policies, and creative mechanisms. In emerging economy like Bangladesh, innovation needs to be given a lot of attention, as the country has experienced political stability and infrastructure development in recent years, resulting in an increase in innovation, foreign investment, and trade, all of which have contributed to economic growth thus offer both local and international businesses new markets and growth opportunities. This study uses three different methodologies including the symmetric ARDL, dynamic ARDL simulations and the asymmetric ARDL for model robustness check to assess how technological innovation, foreign direct investment, trade openness, and human capital affect economic growth in Bangladesh. These methods help us to assess the short- and long-run symmetries, asymmetries, positive and negative shocks of the following variables on economic growth during the period 1990–2020, as well as to learn about the nexus of technological innovation and economic growth, foreign direct investment and economic growth, trade openness and economic growth, and human capital and economic growth. For identifying the optimal lag length, the Augmented Dickey–Fuller and Phillip–Perron tests and Schwarz information criterion (SIC) were used to identify unit roots of the series under consideration. Both long- and short-run bounds tests are conducted to determine whether cointegration exists, and the results confirm the existence of cointegration. Furthermore, the Zivot–Andrews structural break stationarity test has been used to account for structural breaks in the data. Finally, several stability tests are done to see the trend of the model over time. The study concludes based on the mixed results from the

estimation that: (a) The short and long-run effects of the independent variables on the economic development illustrates substantially different results in Bangladesh. (b) In symmetrical approach, the short-run effects being more significant, although, the asymmetrical approach generated mixed results. (c) Long-term economic growth is significantly improved by technological innovation and human capital, but foreign direct investment and trade openness appear to have little impact. (d) Bangladesh economy is substantially affected by technological innovation and trade openness in the short run, but not by foreign direct investment and human capital.

6.2 Policy Implications

Taking into account our empirical findings, we suggest the following policy recommendations. Our research correlation recommends that straightforward forecasts of future development trends in Bangladesh may differ from reality, requiring policymakers and governments to consider broader policy initiatives. As long as the nexus of economic prosperity and all the other factors increases, we expect Bangladesh's economy to grow and prosper, which heavily depends on the effectiveness of the government's policy planning. As a fundamental component of rapid economic growth, macroeconomic stability should form the basis for economic policy direction. In order to spur Bangladesh's rapid growth, policy makers should closely observe the country's economic situation, which is complemented by market orientation and deregulation. After 50 years of independence, Bangladesh needs a change in policy making and implementation procedures that will result in a meaningful shift in its economic direction. We therefore recommend to seek more comprehensive policies which may include: (1) Incorporate Global Innovation into the formulation of economic, innovation, and trade policies to improve infrastructure, technology, inventions, and reduce deficits, focusing on both national and global innovative systems. (2) Developing a legal framework combined with capacity building for innovation prioritizing the establishment of innovation centers, building trainer capacities and skills, and arranging and securing funding for operating costs for green economic activity using more green technology (3) The supply restrictions could be eased with structural reforms aimed at improving productivity and making trading easier while assuring a secure and competitive investment environment. (4) In order to share costs, promote technology research, commercialize innovation, and increase innovation capacity, public and private sector collaboration, resources, and initiatives need to be prioritized. We must therefore ensure prompt and pragmatic policy responses from the relevant authorities in order to maintain a strong economy throughout these uncertain and difficult times.

6.3 Limitations and potential future research areas

While this paper examined the impact of technological innovation, foreign investment, trade openness, and human capital on economic growth, there are still several areas that need to be addressed in future studies. The limitation of this study lies in

the fact that it uses country-level data as a single unit and the lack of research data limits its scope, but there are alternative substitutions which can be used if they are available. Our single indicator of innovation was only able to capture a portion of innovation activities or sectoral expertise in Bangladesh, so we may need to broaden the range of indicators. This means further empirical analysis on the relationship between innovation and economic growth can be done by focusing on the combination of output and input indicators. In order to attract investors looking for a stable and dynamic macroeconomic environment, we must emphasize improving the local workforce's skills and quality, consolidating and improving industrial technologies, and improving our country's image. As part of our efforts to achieve sustainable industrial development, we believe that it is essential to support innovators and creators, and to stimulate building partnerships. A collaboration and linking of universities with local and international research centers, factories, institutions, and production companies in order to implement innovations. To ensure the quality of education at all levels; to deepen and broaden the knowledge, skills, and attitude acquired in the previous stage: enabling the acquisition of new skills and knowledge, and motivating people to contribute to the education system, particularly in primary, secondary, and vocational schools. The goal of future research is to examine the causal and spatial relationships between economic growth and other relevant variables in order to enable successful participation in the globalization process. However, future research should also consider the national innovation system and performance measures. Future Bangladeshi development will depend on the encouragement of more international and domestic investment and innovation opportunities. It is essential that the government carefully plans monetary and fiscal policies to counter external shocks and protect the vulnerable, while creating a green, resilient and inclusive economy.

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Declarations

Conflict of interest The authors have no competing interests to declare relevant to this article's content.

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Authors and Affiliations

Preethu Rahman[1] · Zhihe Zhang[1] · Mohammad Musa[1]

Preethu Rahman
preethu@snnu.edu.cn

Mohammad Musa
musa@snnu.edu.cn

[1] International Business School, Shaanxi Normal University, No. 620, West Chang'an Avenue, Chang'an District, Xi'an 710119, China