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TECHNOLOGICAL INNOVATION, INFRASTRUCTURE AND INDUSTRIAL GROWTH IN BANGLADESH: EMPIRICAL EVIDENCE FROM ARDL AND GRANGER CAUSALITY APPROACH

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ABSTRACT

In this study, we examined the empirical cointegration, long and short-run dynamics and relationships between technological innovation, infrastructure and industrial growth in Bangladesh over the period of 1974–2016. The ARDL Bounds Test methodology and Granger Causality test in an augmented VECM framework were applied. The ARDL bounds tests and additional cross-checking tests, undoubtedly confirmed long run as well as short-run cointegration between the three variables in Bangladesh. The obtained results expressed that infrastructure has a positive impact on the industrial growth but technological innovation has a negative impact on it in the long run. In the short run, infrastructure and technological innovation both have a positive and significant impact on industrial growth. The VECM Granger causality test reveals the existence of a bi-directional causality running between Industrial growth and infrastructure; and infrastructure and technological innovation. On the other hand, unidirectional causality is running from industrial growth to technological innovation. The findings of the Granger causality test supports the results obtained in the ARDL approach in our study. The results obtained from this empirical analysis have an important policy implication for a developing country like Bangladesh as well as other developing countries.

1. INTRODUCTION

The founding partner, Roger McNamee, of the Venture Capital Firm Elevation Partners of US, commented that "We need to stop thinking about infrastructure as an economic stimulant and start thinking about it as a strategy. Economic stimulants produce Bridges to Nowhere. Strategic investment in infrastructure produces a foundation for long-term growth". In the same paper, investigation conducted on 'Industry and Infrastructure' of India, it was revealed that vital factors for economic growth and development are to promote inclusive employment-intensive industry and to build resilient infrastructure (Hogan and McNamee, n.d). So there is a close relationship between infrastructure and industrial development or Economic development. All the activities of human being are somehow related to economic development and industrial development is one of the major components of it Rahman and Kashem (2017). From the economic growth point of view, the world has achieved a significant development in different kinds of infrastructure as the roads, railroads, airlines, giant bridges, high rise skyscrapers, tunnels, and industries etc. According to Ayeche *et al.* (2016) the global economic system has experienced the tremendous success of industrialization and technological innovation in the twentieth century with the size of wealth more than twenty times.

The Researchers Ameer and Munir (2016) demonstrated that it is so fascinating to see how technology, trade openness, urbanization, economic growth, and environment are working together as well as against each other at the same time. Technological advancement has lowered the cost of transportation and communication. In current research (Brock and Taylor, 2010; Kang *et al.*, 2016) commented that the technology is a way of bringing the world closer and helps to resolve problems. It is found that environmental degradation rises with economic growth but fall with on-going technological progress. Mentioning the study of WTO in 2013, Were (2015) revealed that Globalization is characterized not only intensive trade integration and trade openness but also associated with technological revolution. Advances in technology, telecommunications and transport have created opportunities for a reorganization of global production and distribution system (Industrial development). So there is a close relationship between technological innovation, infrastructural development and industrial growth.

Now it will be logical to describe in brief about the present economic development status of Bangladesh. She is a small (lower) middle income country of more than 161.5 million people in South Asia became independent in 1971. GDP of Bangladesh is 227.9 billion USD, GDP per capita 1411.00 USD, GDP as the percent of World GDP is 0.52 which is the 33 largest economy in the world (According to market size 38th) (Schwab, 2017). (Global Competitiveness Index 2017-18, World Economic Forum). Industrial Value added of Bangladesh is $60.55 billion and Industrial Value added as percent of GDP is 28 percent (The Global Economy, 2018). So one-third of the economic growth is coming from Industrial growth approximately. In spite of facing many natural calamities like floods, droughts, cyclones, tsunami, etc. and many man-made disturbances as political instability, overpopulation, corruption, terrorism, etc., the economy of Bangladesh is maintaining a respectable growth. This progress is a miracle to the world leaders, scholars, experts and international development bodies like WB, WTO, IMF, UNESCO, etc. Bangladesh is achieving around 5.9% percent growth in GDP from 1994 to 2016. GDP growth of Bangladesh in 2016-17 financial year is 7.24 percent which is over China and below India. The sectors which are playing very important role in achieving this high performance are the manufacturing, services, private consumption and public investment (World Bank, 2017).

According to the publication of World Bank (2017) the share of the population living under the poverty line fell from 31.5 percent in 2010 to 24.3 percent in 2016-17. Between 2003 and 2016 the Bangladesh economy generated more than 1.15 million net jobs per year and employment growing 2.4 percent annually. In this matter, industrial development is keeping great contribution to reduce the unemployment problem as well as in the poverty alleviation. Trade integration through exports in the ready-made garments (RMG) sector has been a critical catalyst of job-creating industrialization and urbanization. Bangladesh ranked 2nd position in the ready-made garments (RMG) export in the world and China is the first in this sector. The RMG sector of Bangladesh is contributing about 80% of the total export. The other major industrial sectors of Bangladesh are Chemical, Pharmaceutical, Tannery, Cement, Food and Fertilizer Industry. Bangladesh continues to be one of the largest recipients of remittances in the world which has been keeping an important contribution to the balance of payments.

According to the report of Global Competitiveness Index (GCI) of World Economic Forum published in 2017, the ranking of Competitiveness of Bangladesh (overall) has improved in 99th which was 106th in 2016 (Seven up) among 137 countries. She has improved the scores across all pillars of competitiveness. On the other hand, this body stated that development of ICT infrastructure and ICT use remained still the biggest challenges for the country. Not only Bangladesh but also total South Asia is the region where technological readiness stagnated extremely. According to the estimation of this institution, the ranking of Bangladesh in infrastructure, macroeconomic environment, technological readiness and innovation are 111th, 56th, 120th and 114threspectively out of 137 countries (Schwab, 2017). According to the Global Economy Report Bangladesh ranked 41st position among 158 countries and in Industrial Value added as the percent of GDP she ranked 71st position (TGE, 2018). So

Bangladesh remains far behind from the world standard of infrastructure development, technological progress as well as industrial development. Besides, GCI calculated 'inadequate supply of infrastructure' as the 2nd "Most problematic factors for doing business" in Bangladesh and 'Corruption' is the first problem.

It could be mentioned here that the development of industrial and manufacturing sectors of Bangladesh is going on under unplanned installation of industries in the surrounding areas of Dhaka and Chittagong city. As a result, scattered and unplanned urbanizations and environmental degradation are taking place. So development process is going on but at the cost of the environmental problem and major negative impact on public health (Rahman and Kashem, 2017; Sarkar *et al.*, 2017).

By reviewing the past literature we found that most of the researchers showed the positive impact of different kinds of infrastructures on economic growth. In the studies conducted on Bangladesh by Khandker *et al.* (2006); Khandker and Koolwal (2006); Khandker *et al.* (2009); Ghosh *et al.* (2010); Sawada (2012); Mahmud and Sawada (2015); Sawada *et al.* (2017); Khandker and Samad (2018) demonstrated that physical (economic) infrastructure such as bridges, telecommunications, roads, rural roads, financial institutions, water supply, sewage systems, irrigation, electricity, gross capital formation; and social infrastructures like hospitals and school facilities have reduced poverty and increased over all economic growth. The investigations conducted at international level also illustrated the positive effect of infrastructures on economic growth (Aschauer, 1989; Hulten and Schwab, 1991; Easterly and Rebelo, 1993; Ramanathan, 2001; Calderón and Servén, 2004; Dollar *et al.*, 2005; Hulten and Isaksson, 2007; Fedderke and Bogetić, 2009; Dethier *et al.*, 2010; Fleisher *et al.*, 2010; Pradhan and Bagchi, 2013; Achour and Belloumi, 2016; Chingoiro and Mbulawa, 2016; Udah and Bassey, 2017).

There are some studies which found negative or mixed results of different infrastructure proxies on different macroeconomic variables of economic growth (Day and Zou, 1994; Evans and Karras, 1994; Gramlich, 1994; Holtz-Eakin and Schwartz, 1994; Ferreira and Issler, 1995; Bougheas *et al.*, 2000; Brenneman and Kerf, 2002; Okoh and Ebi, 2013; German-Soto *et al.*, 2017).

There is a large and growing body of literature which has investigated the technology - growth relationships and most of the researchers found the positive impact of technology on economic growth. The investigations conducted by Hardy (1980); Madden and Savage (1998); Stiroh (2002); Brynjolfsson and Hitt (2003); Fabiani *et al.* (2005); O'Mahony and Vecchi (2005); Garbacz and Thompson (2007); Koutroumpis (2009); Gruber and Koutroumpis (2010); Vu (2011); Ahmed and Ridzuan (2013); Sassi and Goaied (2013); Chester *et al.* (2014); Sohag *et al.* (2015); Shahbaz *et al.* (2016); Kumar *et al.* (2017); Sarkar *et al.* (2017) revealed that different proxies of technology like technological innovation, ICT, broadband connection, telecommunications, mobile telecommunications, mobile cellular technology, financial openness, patents have positive effect on economic growth.

Some of the scholars discovered the negative or mixed impact of technology on economic growth (Lee *et al.*, 2005; Ishida, 2015; McCartney, 2017).

The study has the following specific objectives:

a) To analyze the short-run and long-run relationships of technological innovation and infrastructure on the Industrial growth of Bangladesh.
b) To analyze the direction of causality (no directional, Unidirectional or bidirectional/feedback) between technological innovation and infrastructure, infrastructure and technological innovation; technological innovation and industrial growth, industrial growth and technological innovation; Industrial growth and infrastructure, infrastructure and industrial growth.
c) To find out the policy implication for Bangladesh Government in order to formulate national technological policy, Industrial policy and Infrastructural policy to foster economic growth by policy coordination at the national and international level.

By reviewing the existing literature, we observe that numerous researcher conducted lots of study taking different variables as GDP, CO_2 emissions, energy consumption, financial sector development, income, income inequality, trade openness, technological innovation, infrastructure, Industrial growth or development, etc. and they have used different methods. However, few research works have been conducted in respect of Bangladesh. So far as our findings, we have studied the relationships of technological innovation, infrastructure and Industrial growth of Bangladesh for the first time. The principle contributions of this study in the current literature are: first, it examined the short-run relationships and long-run dynamics among technological innovation, infrastructure and Industrial growth in Bangladesh for the period of 1974–2016 applying ARDL cointegration bound testing approach and VECM Granger causality testing method. Second, most updated and longest time series data (1974–2016) from world-renowned source 'World Development Indicators' of World Bank have been used in this study. Third, though most of the previous studies used GDP as the proxy of economic growth but we have used industrial value added as a proxy of economic development in the research (Rahman and Kashem, 2017) and fourth the empirical result of this study would provide policymakers of Bangladesh a better understanding of technological innovation, infrastructure and industrial growth nexus to formulate technological, Industrial and infrastructural policy to foster economic growth by policy coordination at the national and international level. For this reason, this research holds great importance in the literature arena and will fill up the gap in the existing economic literature to the relationships between technological innovation, infrastructure and Industrial growth.

The remaining part of the paper is designed in the following way: Section 2 describes the review of the past literature; Section 3 reveals the data construction; Section 4 presents the methodology of the study; Section 5 illustrates the estimation, findings, analysis and discussion; Section 6 concluded the paper and suggested some important policy implications of this study for Bangladesh which is also applicable to other developing countries.

2. LITERATURE REVIEW

There is a large volume of published studies which have analyzed empirically the relationships between technological innovation, infrastructure and Industrial development. A growing body of literature has investigated the infrastructure - economic growth relationships and most of the researchers found the positive impact of infrastructure on economic growth. First, we are going to summarize the literature on Bangladesh. In the single country study conducted by Khandker and Koolwal (2006) on Bangladesh, investigated the impact of infrastructure development on pro-poor growth. Applying quantile regression techniques, they showed that implementing certain policies growth in overall income reduces poverty, as well as infrastructure development, has the higher impact on extreme poverty reduction compared with moderate poverty reduction. In a similar study in the same year conducted by the World Bank, the researcher (Khandker *et al.*, 2006) revealed the importance of rural roads in Bangladesh. Their study demonstrated that 6 percent poverty declined in the road development project areas. The similar result was found in the study of Khandker *et al.* (2009); Khandker and Samad (2016).

Bangladesh is a country full of rivers, canals, bills and haors (One kind of big lake). So bridge infrastructure is very much crucial for the economic development of the country (Sawada, 2012; Mahmud and Sawada, 2015). The Jamuna Bridge built on the second largest river Jamuna has contributed to the economic growth and poverty alleviation of Bangladesh by reducing the regional gaps in the living standard between the east and the west (Ghosh *et al.*, 2010). Similarly, Mahmud and Sawada (2015) revealed the positive impact of the bridge on employment opportunities. In a recent study, Khandker and Samad (2018) revealed that investment in infrastructure in Bangladesh increases economic activity, enhances productivity and efficiency in production, consumption, and distribution. They also showed that increased productivity raises income and bolsters the technology available for economic development.

In the international level, the study of Aschauer (1989) demonstrated that non-military public expenditure in infrastructure is more important in determining productivity growth as well as physical infrastructure like roads and other transportation networks, sewer and water systems etc. Mentioning the study of the World bank in 1994 Shahbaz *et al.* (2017) revealed that a 1% increase in the stock of infrastructure was equivalent to a 1% increase in gross domestic product (GDP) across all countries in 1990s. Easterly and Rebelo (1993) revealed that public investment in transport and communication has a positive correlation with growth. The same kind of findings was revealed in the study of Dollar *et al.* (2005); Hulten and Isaksson (2007); Fedderke and Bogetić (2009).

In a study by Hulten and Schwab (1991) indicated that increase in electricity generating capacity could expand product quality and also added that competition and specialization intensify total factor productivity. Utilizing enterprise surveys of 70,000 firms in over 100 countries around the world, Dethier *et al.* (2010) investigated the impact of infrastructure, finance, security, competition and regulation on productivity and growth in developing countries. The result of their study revealed the significant positive impact of these variables on productivity and growth. In a comprehensive study on regional differences in China (Fleisher *et al.*, 2010) revealed that investment in infrastructure creates higher returns in the developed Eastern region of China than the underdeveloped areas.

In the single country study, Binswanger *et al.* (1989) showed the positive impact of roads in India's rural economy and added that roads play an important role in marketing and distribution of agricultural goods as well as curdles the transportation costs. The same result was documented in the study of Samimi (1995); Ramanathan (2001); Calderón and Servén (2004); Raychaudhuri (2004); Ghosh and De (2005). In line with these studies, Barnes and Binswanger (1986) showed the positive effect of rural electrification on agricultural productivity in India. Reviewing of World Bank sponsored 28 electrification projects, Group (2008). (The World Bank, Independent Evaluation Group – 2008) documented that the rich are more benefitted than the poor from the projects.

An investigation conducted by Fedderke *et al.* (2006) on South Africa demonstrated that infrastructure had both a direct and an indirect impact on output. The empirical evidence in his study found a positive effect of infrastructure provision on productivity and growth. The same findings were identified in the research of Fedderke and Bogetić (2009); Roland-Holst (2009); Pradhan and Bagchi (2013).

Further in a study in 14 Asia-Pacific countries at different stages of development (Raychaudhuri and De, 2016) asserted the impact of trade openness and infrastructure on income inequality. On the contrary, they showed that the reverse effect does not exist. A recent study in Tunisia (Achour and Belloumi, 2016) documented that unidirectional long-run causality running from transport value added, road transport-related energy consumption, transport CO_2 emissions and gross capital formation to road infrastructure. The result of their analysis revealed that unidirectional long-run causality is running from railway infrastructure, the transport value added, gross capital formation and transport CO_2 emissions to rail transport related energy consumption. They also showed the short run causality between the variables.

Applying Granger causality approach (Chingoiro and Mbulawa, 2016) demonstrated that bidirectional causality is running between economic growth and infrastructure in Kenya. Applying OLS estimation technique and Engle-Granger two-step co-integration testing approach (Udah and Bassey, 2017) revealed that gross domestic investment, electricity supply, and trade openness are the necessary components to increase the speed of industrialization in Nigeria.

The Outcome Report of the Summit held in Singapore in 2017 (Report, 2017) headed 'New Solutions for Global Infrastructure' suggested that the world needs to invest an average of $3.7 trillion per year, or 4.1 percent of gross domestic product (GDP) in the economic infrastructure until 2035 to keep pace with projected economic and population growth and bridging global infrastructure gaps which is more important than ever. In that report, global leaders suggested that a long-term planning should be needed for global infrastructure development; make better use of digital technology; and evolve the public-sector procurement process to focus on out of innovation.

There are some studies which found the mixed or negative results of different infrastructure proxies on different macroeconomic variables. In several research the relationships between infrastructure and productivity or total factor productivity cannot be ruled out because of the attribution problems of data (Evans and Karras, 1994; Gramlich, 1994; Holtz-Eakin and Schwartz, 1994). The study of Bougheas *et al.* (2000) showed that the impact of public expenditure on economic growth has not been very successful. Similar results were found in the study of Day and Zou (1994); Holtz-Eakin and Schwartz (1994); Ferreira and Issler (1995). In an empirical study conducted on Vietnam, Songco (2002) reveals that infrastructural investment did not have any direct impact in the life of rural communities of Vietnam and suggested for the complementary investments in infrastructure capital to enable community-driven infrastructure selection to reduce rural poverty. The Researcher Brenneman and Kerf (2002) documented that infrastructure like transport and energy services expanded education and water/sanitation, on the contrary, they did not find any impact of telecommunications in these sectors.

Evaluating 102 studies conducted during the past 15 years, policy research financed by World Bank (Garmendia *et al*., 2004) demonstrated that the impact of infrastructure is more prominent in developing countries than in developed countries. They found that infrastructure has a mixed effect in the US but the significant positive impact in the economic growth of Spain as well as developing countries. In a similar kind of study, Okoh and Ebi (2013) indicated that infrastructure investment has a positive impact on economic growth. On the contrary, the relationships between infrastructure investment and institutional quality on economic growth had been insignificant because of the corruption. The study conducted by German-Soto *et al.* (2017) in Mexican urban areas reveals that certain kinds of infrastructure variables like water supply, road infrastructure, vehicle density, highways, and a social infrastructure index have no significant impact on economic growth.

The role of technology in economic growth has been explained in the neoclassical growth theory introduced by Solow (1956). Technology has been considered as a crucial factor of various types of economic activities and it has transformed the economy as knowledge-based (Romer, 1990; Oulton, 2012). A large and growing body of literature has investigated the technology - economic growth relationships and most of the researchers found the positive impact of technology on economic growth.

By reviewing past literature and presently available data on Bangladesh, McCartney (2017) revealed that Bangladesh is going to fall into the 'middle-income trap'. Using the Unequal Exchange theory of Dependency School, he commented that the ideas of productivity, competitiveness and technological change are not useful in understanding economic growth perspective and policy responses in contemporary middle-income countries like Bangladesh.

In the previous study Hardy (1980) empirically confirmed that telephones contribute to the economic development taking 60 countries. By using the data of 27 Central and Eastern European (CEE) countries (Madden and Savage, 1998) found a positive relationship between investment in telecommunication infrastructure and economic growth. In an investigation, Garbacz and Thompson (2007) demonstrated that penetration of telecommunication services increases the productive efficiency around the world and especially in low-income countries. Brynjolfsson and Hitt (2003) confirmed that firms that have invested in computer technology had been able to realize higher productivity.

In their study Hu (2005) investigated the data of 8 US industries and confirmed the Technology-growth hypothesis. Using industry-level data (O'Mahony and Vecchi, 2005) showed a positive effect of ICT on output growth and excess returns relative to the non-ICT assets. Similarly, Fabiani *et al.* (2005); Atzeni and Carboni (2006) examined the data of Italian manufacturing firms and demonstrated that ICT investments have a stronger effect on productivity. The similar results were documented in the study of Stiroh (2002); Seo *et al.* (2009); Vu (2011); Chavula and Chekol (2013); Sassi and Goaied (2013); Vu (2013).

The researcher Koutroumpis (2009) revealed that broadband penetration has a positive causal linkage with economic growth in 22 OECD countries. In a study, Gruber and Koutroumpis (2010) stated the significant effect of mobile telecommunications diffusion on GDP and productivity growth for 192 countries. Using a panel of 98 countries (Castellacci and Natera, 2013) showed that the dynamics of national innovation system is driven by the innovative capability like technological output, scientific output, and innovative output.

In a detailed study, Ahmed and Ridzuan (2013) investigated the impact of ICT on economic growth for ASEAN5+3 countries, revealed that labor, capital and telecommunications investment have positive relationships towards GDP. The study conducted the effects of technological innovation on energy use in Malaysia, Sohag *et al.* (2015) documented that increasing GDP per capita and trade openness produce a rebound effect of technological innovation on energy use. To determine the relationships between ICT, economic growth and electricity consumption in UAE, Shahbaz *et al.* (2016) found that ICT increases electricity demand and there is a feedback or bi-directional effect exists between economic growth and electricity consumption.

By utilizing the extended Cobb–Douglas type Solow framework and the ARDL bounds testing approach (Kumar *et al.*, 2017) revealed that mobile technology has a positive short-run and long-run impact on the output per capita and a bi-directional causality existing between mobile cellular technology and output per capita in Zimbabwe. In a study on Bangladesh's industrial sector, Sarkar *et al.* (2017) commented that an Industrialization is an essential tool for accelerated economic growth for an emerging country like Bangladesh. Their study indicates that significant industrial growth has a substantial effect on the economic development, public safety, health and environment of the country.

Some of the scholars discovered the mixed or negative impact of technology on economic growth. In a study Lee *et al.* (2005) demonstrated that ICT has a positive effect in the economic growth in many developed countries and newly industrialized economies (NIEs) but not in developing countries. Another single country study (Ishida, 2015) examined the nexus between ICT investment, energy consumption and economic growth in Japan. The result obtained from their experiment concluded that ICT investment contributes to a moderate reduction in energy but does not increase GDP. In a review study conducted by Chester *et al.* (2014) revealed the role of infrastructure and technologies in cities and their contribution to greenhouse gas (GHG) emissions should be reevaluated and considered again.

By reviewing the existing literature, we observe that numerous researcher conducted many studies taking different variables as GDP, CO2 emissions, energy consumption, financial sector development, income, income inequality, trade openness, technological innovation, infrastructure, industrial growth or development etc. and they have used different methods. But few researchs have been operated in the case of Bangladesh. So far as our findings, we have studied the relationships of technological innovation, infrastructure and industrial growth of Bangladesh for the first time. For this reason, this research holds a great importance in the literature arena and will fill up the gap in the existing economic literature to the relationships between technological innovation, infrastructure and Industrial growth.

3. DATA CONSTRUCTION

In order to investigate the relationships between three important macroeconomic variables technological innovation (TI), infrastructure (INF) and Industrial Development (IND) of Bangladesh, data have been taken from the world renowned data source 'World Development Indicators' of the World Bank published in 2017. It has covered the period from 1974 to 2016 which is the longest time series data being used so far. For Industrial development (IND), we have used Industrial value added (constant 2010 US$). It could be mentioned here that Industrial value added has been used as the proxy for economic development of Bangladesh (Rahman and Kashem, 2017). For technological innovation (TI), we have taken the number of patents applied by residents and non-residents (sum) as a proxy of it. It can be mentioned that technological innovation indicates the interest of industrial and private organizations of a country in exploring a new technology and could be reflected by a quantitative indicator, such as the number of patents. In this situation, following the empirical studies of Ang (2009); Tang and Tan (2013); Sohag *et al.* (2015); Cederholm and Zhong (2017) in our research, we have also considered the number of patents as a proxy for technological innovation. For infrastructure (INF) variable, different researchers have used different proxies. Chingoiro and Mbulawa (2016) used WDI Index, but WDI has the index of infrastructure for African Countries, not for all the countries of the world. German-Soto *et al.* (2017) used 'Global Infrastructure Index' which has the index only for 27 countries. Pradhan and Bagchi (2013); Achour and Belloumi (2016) have utilized Per capita Gross capital Formation data of WDI. Following them, we have also used Gross capital formation (constant 2010 US$) as the proxy of infrastructure (INF) for Bangladesh. We have converted all-time series data to their natural logarithm form.

4. METHODOLOGY

4.1. Theoretical Framework and Model

In our empirical study, we have utilized the Cobb–Douglas production function expressed in the Solow Model (Solow, 1956) to analyze the relationships among technological innovation, infrastructure and industrial growth of Bangladesh. We know that the Cobb–Douglas production function is widely used in economics to present the relationship between inputs and output (Kahia *et al.*, 2016; Kahia *et al.*, 2017).

The general production function has been expressed in the following way:

$$Y = f(K, L) \quad \text{-------- (1)}$$

Where Y is the total production, K is the capital input, L is the labor productivity which is constants and determined by available technology.

The Cobb–Douglas production function is:

$$Y = A\ f(K,L) \quad \text{-------- (2)}$$

$$Y = \left(AK^{\alpha}L^{\beta}\right) \quad \text{-------- (3)}$$

Here A is the parameter of Technology and α and β are the output elasticities of capital and labor.

Solow converted the Cobb–Douglas production function in the following way:

$$Y = f(K, L \times E) \quad \text{-------- (4)}$$

Here E is the Efficiency of labor which is integrated with the Technology. So on the basis of Cobb–Douglas production function expressed in the Solow Model (equation (3) and (4)) and following the study of Siddique and Majeed (2015); Jamel and Maktouf (2017) our general linear equation for three macroeconomic variables - technological innovation, infrastructure and Industrial development stands as follows :

$$IND_t = \propto_0 + \propto_1 TI_t + \propto_2 INF_t + \varepsilon_t \quad \text{-------- (5)}$$

Where *IND* refers as the Industrial value added which has been used as a proxy of Industrial development, *TI* denotes the technological innovation and *INF* refers infrastructure, $\propto_0$indicates the constant, $\propto_1$ and $\propto_2$refers the coefficient of the variables, ε_t measures the residual term. The subscript t is the time period. By taking the natural logarithm of the variables in both sides the equation stands as follows:

$$lnIND_t = \propto_0 + \propto_1 lnTI_t + \propto_2 lnINF_t + \varepsilon_t \quad \text{-------- (6)}$$

4.2. Unit Root Testing

In our study, we will apply two kinds of unit root tests: a. Traditional unit root test and b. Unit root with structural break. ADF Test and PP testing methods would be used to determine the traditional unit root of the variables and modified ADF for structural break unit root tests. Though unit root test is not necessary in the ARDL approach, because of this method could operate the unit root test in the presence of cointegration among the variables of order *I(0)* or *I(1)*or a mix of it. The researcher Pesaran and Shin (1998) and Pesaran *et al.* (2001) expressed that in ARDL Bounds Test none of the variables should be integrated in the order *I(2)*. If the variables are integrated in the order *I(2)*, it would invalidate the methodology of the test. For this reason, it is important to justify the stationarity of time series variables before moving to the next level of analysis. According to the suggestion of Pesaran and Shin (1998) and Pesaran *et al.* (2001) Augmented Dickey-Fuller (ADF) and the PP unit root testing methods would be utilized to test the normal unit roots of the variables in our study.

According to the conventional unit root testing approach, it is assumed that random shocks would have only temporary effects and would not affect in the long-run on the economy. In their study, Nelson and Plosser (1982) argued that economic fluctuations are not temporary and random shocks have a permanent effect on the economy. Barros *et al.* (2011) revealed that macroeconomic variables like GDP, industrial growth etc. faces structural changes, particularly in the developing countries. In addition, according to Perron (1989) traditional unit root tests such as ADF provides biased results in the presence of structural break. Taking these things into consideration, we checked structural breakpoints using (Bai and Perron, 2003) multiple breakpoint tests and we would again conduct structural break unit root tests in the modified ADF test.

4.3. Test of Cointegration in ARDL Bounds

There are various methods to test the presence of the cointegration and the short-run and long-run relationships between or among the variables. We would use the ARDL Bounds Testing approach in our study. It is well known that the ARDL bound testing approach has a number of attractive features over conventional cointegration testing methods. The features are: (a) this method has the superiority on other methods and permits to analyze the data in the presence of cointegration of I(0) or I(1); (b) it has theflexibility and for single equation set up it could be easily implemented and interpreted; (c) it could be utilized for small observations; (d) in this technique different lag-lengths for different variables could beused; (e) unbiased result of short-run relationshipsand long-run dynamics of the parameters are presented in this method and (f) it removes the autocorrelation and endogeneity problems so far as possible.

In ARDL method, the error correction model results illustrate the speed of adjustment back to the long run equilibrium after a short run shocks. The ECM integrates the short-run coefficient with the long-run coefficient without losing long-run information. Under ECM technique, the long run causality is depicted by the negative and significant value of the error correction term (ECT) coefficient and the short run causality is shown by the significant value of coefficients of other explanatory variables (Shahbaz, 2012; Shahbaz *et al.*, 2013; Rahman, 2017; Rahman and Kashem, 2017). Following the above mentioned researchers for bounds testing of cointegration, the ARDL model used in this study is:

$$\Delta lnIND_t = \propto_{10} + \sum_{i=1}^{\rho} \propto_{11} \Delta lnIND_{t-i} + \sum_{i=1}^{\rho1} \propto_{12} \Delta lnTI_{t-i} + \sum_{i=1}^{\rho2} \propto_{13} \Delta lnINF_{t-i} + \beta_1 \Delta lnIND_{t-1} + \beta_2 \Delta lnTI_{t-1} + \beta_3 \Delta lnINF_{t-1} + \beta_4 DUM + \varepsilon_t \quad \text{----------- (7)}$$

In the model produced above, IND, TI and INF are the variables of our study. This model is a unique type of Error Correction Model (ECM) and the coefficients of the model are not restricted here. In the model ε_t is well-behaved random disturbance terms which is serially independent, homoskedastic and normally distributed. Pesaran *et al.* (2001) described this special type of ECM as the conditional ECM. The terms mentioned in the model with summation signs represent the error correction dynamics for the short run and the terms with β referred to the long-run relationships among the variables (Rahman, 2017; Rahman and Kashem, 2017). The maximum lag lengths ρ, $\rho 1$ and $\rho 2$ for the model would be determined by using one or more of the 'information criteria' such as AIC, SC, HQ, etc. DUM is the dummy variable to absorb or capture the structural break based on the modified ADF unit root tests. According to the result of structural break, we have used dummy variable to stabilize the model. The null and alternative hypotheses of the above mentioned equation would be as follows:

H0: No cointegration exists.

H1: Cointegration exists.

The null hypothesis of the model would test by utilizing F-test for the joint significance of the coefficients of the lagged values of the variables. Thus the null and alternative hypothesis for model is as follows:

H0 : $\beta_1 = \beta_2 = \beta_3 = 0$

H1 : $\beta_1 \neq 0, \beta_2 \neq 0, \beta_3 \neq 0$

About the bounds testing method, Pesaran *et al.* (2001) developed the critical values of the F-statistic for the asymptotic distribution. In this technique, they introduced lower and upper bounds on the critical values for various situations. According to their explanation, there is no cointegration between or among the variables whether the computed F-statistic falls below the lower bound. If it exceeds the upper critical value, a long run relationship is running. If it falls between the bounds, the test result is inconclusive.

In this analysis short-run parameters will be estimated by applying the regular error correction mechanism (ECM) expressed in the Model produced above (equation (7)):

$$\Delta lnIND_t = \propto_{10} + \sum_{i=1}^{\rho} \propto_{11} \Delta lnIND_{t-i} + \sum_{i=1}^{\rho 1} \propto_{12} \Delta lnTI_{t-i} + \sum_{i=1}^{\rho 2} \propto_{13} \Delta lnINF_{t-i} + \beta_{14} DUM + \gamma_1 ECT_{t-1} + \varepsilon_t \quad \text{---------- (8)}$$

In equation (8) ECT is the special error correction term under the error correction model. It has been mentioned earlier that results would indicate the speed of adjustment back to the long run equilibrium after a short run shock. In addition, the long run causality is expressed by the negative and significant value of the error correction term (ECT) coefficient γ and the short run causality is shown by the significant value of coefficients of other explanatory variables (Shahbaz *et al.*, 2013; Rahman and Kashem, 2017).

4.4. Diagnosis Test of the Model

In this study, we would use the traditional techniques to diagnosis the model. According to the ARDL Bounds testing approach, it is essential and crucial assumptions are that the errors of equations (7), (8) and (9) must be identically and independently distributed (iid). In order to identify the Serial Correlation problem 'Breusch-Godfrey Serial Correlation LM test', to test the Normality of the errors of the model 'Jarque-Bera' test would be utilized. Finally, 'Breusch-Pagan-Godfrey' test will be used to analyze the heteroscedasticity of the model.

4.5. Stability Test of the Model

The model which has the autoregressive characteristics in nature is essential to ensure the dynamic stability of it. According to the suggestion of Pesaran and Pesaran (1997) and following Brown *et al.* (1975) recursive CUSUM and CUSUM of squares tests would be used to check the stability of the model.

4.6. Granger Causality Test

We are going to use the ARDL approach to analyze the cointegration, short-run relationships and long-run dynamics between the variables in this study. But Granger (1969) suggested that it is not enough only to measure the correlation between or among the variables. The reason is that there might be the existence of a third variable and obtained results of correlations can be spurious and useless. Unidirectional, bi-directional or no-directional Granger causality may be present in case of two or more time series variables are cointegrated. Besides, only correlation does not confirm causation between or among variables. So on the basis of above discussion; we should go for a cross-check of our findings. In this study we would use the Granger causality test to determine the relationships and the directions of our variables again. When co-integration exists between the variables, there exists an ECM. We can examine the ECM by applying Engle-Granger causality approach. According to this approach, a change independent variable is regressed on the independent variables using different form and optimal lag lengths. Following Siddique and Majeed (2015); Destek *et al.* (2016) the VECM is expressed in the equations below:

$$\Delta lnIND_t = \propto_{10} + \sum_{i=1}^{\rho} \propto_{11} \Delta lnIND_{t-i} + \sum_{i=1}^{\rho 1} \propto_{12} \Delta lnTI_{t-i} + \sum_{i=1}^{\rho 2} \propto_{13} \Delta lnINF_{t-i} + \gamma_1 ECT_{t-1} + \varepsilon_{t1} \quad \text{---------- (9)}$$

$$\Delta lnTI_t = \propto_{20} + \sum_{i=1}^{\rho} \propto_{21} \Delta lnTI_{t-i} + \sum_{i=1}^{\rho 1} \propto_{22} \Delta lnIND_{t-i} + \sum_{i=1}^{\rho 2} \propto_{23} \Delta lnINF_{t-i} + \gamma_2 ECT_{t-1} + + \varepsilon_{t2} \quad \text{---------- (10)}$$

$$\Delta lnINF_t = \propto_{30} + \sum_{i=1}^{\rho} \propto_{31} \Delta lnINF_{t-i} + \sum_{i=1}^{\rho 1} \propto_{32} \Delta lnIND_{t-i} + \sum_{i=1}^{\rho 2} \propto_{33} \Delta lnTI_{t-i} + \gamma_3 ECT_{t-1} + \varepsilon_{t3} \quad \text{---------- (11)}$$

Here in the above equations Δ is used for the first difference, α is intercepts, ρ is for appropriate lag length, ε for error term. ECT is the error term and γ is the coefficient of ECT. γ is obtained by the residuals estimated of equations. The coefficients of explanatory variables describe variation in short run and causality. The EC terms interpret long-run causality and error adjustments. We will determine the appropriate maximum lag length for the variables in the VECM by using the usual methods. Specifically, basis of the choice of lag length is on the usual information criteria, such as AIC. We will also ensure that VECM is well specified; that is VECM does not contain serial correlation in the residuals.

5. RESULT ANALYSIS AND DISCUSSION

We started our analysis with the simple statistical tools as descriptive statistics and correlation matrix. The findings have been presented in Table (1).

Table-1. Descriptive Statistics and Correlation of Variable

Variables	IND	INF	TI
Mean	1.48E+10	1.44E+10	213.7750
Median	1.03E+10	8.95E+09	169.0000
Std. Dev.	1.25E+10	1.33E+10	88.45004
Jarque-Bera	10.85489	9.390679	4.601103
Probability	0.004394	0.009138	0.100204
Correlation			
lnIND	1.000000		
lnINF	0.990847	1.000000	
lnTI	0.784400	0.746022	1.000000

The table (1) above demonstrated the mean, median and standard deviation of the series. The findings of the Jarque–Bera test shows that the residuals or error terms of the variable technological innovation is normal but it is not normal in case of industrial development and infrastructure. We know that this is not a problem for our analysis. The correlation matrix indicates a significant positive correlation between technological innovation, infrastructure and Industrial development. It is observed that industrial development is highly and positively correlated with infrastructure.

5.1. Unit Root Testing

In order to test the stationarity characteristics of time series data numerous unit root tests are available. They are ADF, PP, DF-GLS, KPSS, ERSPO, Ng-Perron and also some other special unit root tests as Zivot–Andrews unit root test. According to the discussion in the methodology section, we have used the ADF and PP unit root tests in our study and the obtained results have been presented in Table: 2.

Table-2. ADF and PP unit root test.

Variable	ADF (Level)		ADF (First Difference)		PP (Level)		PP((First Difference)	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend
lnIND	5.9021 (1.0000)	0.8284 (0.9997)	-1.1318 (0.6928)	-8.9443*** (0.0000)	4.3118 (1.0000)	-3.8514** (0.0233)	-9.4395*** (0.0000)	-27.447*** (0.0000)
lnINF	-0.5815 (0.8639)	-2.4698 (0.3402)	-3.7765*** (0.0074)	-4.1759** (0.0126)	-0.5802 (0.8642)	-2.1458 (0.5062)	-7.2517*** (0.0000)	-7.5726*** (0.0000)
lnTI	-1.3632 (0.5898)	-4.7572*** (0.0035)	-7.2187*** (0.0000)	-1.5503 (0.7908)	-1.0299 (0.7327)	-2.9925 (0.1475)	-9.4347*** (0.0000)	-9.2581*** 0.0000

*, ** and *** indicate statistical significant at the 10%, 5% and 1% level respectively.

The findings of ADF test indicates that among the three variables only lnTI is significant at 1% level *I*(0) and two others are not significant. However, three variables are significant at 1% in first difference *I*(1). Following the ADF test, PP Test also refers that three variables are significant at 1% in first difference *I(1)*. In addition, lnIND is significant at 5% in level *I(0)*. The results obtained from the ADF and PP unit root tests indicate that the order of integration of the variables are mix of *I*(0) and *I*(1) but none of them is significant at *I*(2). So these results fulfill the conditions to use the ARDL approach in our study.

In line with the discussion of our unit root methodology section, since Barros *et al.* (2011) revealed that macro economic variables experience structural changes particularly in the developing countries. In addition, Perron (1989) commented that traditional unit root tests such as ADF provides biased results towards the non-rejection of the null hypothesis of a unit root in the presence of structural break, we checked structural break points applying Bai and Perron (2003) multiple breakpoint tests and the result is in the table: 3 below.

Table-3. Bai-perron Multiple Breakpoints date.

lnIND		**lnINF**		**lnTI**	
No of Breaks	Break dates	No of Breaks	Break dates	No of Breaks	Break dates
3	1996, 2007, 1985	4	1996, 1981, 2006, 1987	1	1998

The calculated F-statistic of break tests is significant at 5% level as provided by Bai-Perron (Econometric Journal, 2003) critical values.

The results of the table indicate that there are 3, 4, 1 structural breaks of the variables industrial growth, infrastructure and technological innovation in the years 1996, 2007, 1985; 1996, 1981, 2006, 1987 and 1998 respectively. Then we conducted structural break unit root tests in the modified ADF test and the results are as follows (Table: 4):

Table-4. Unit Root tests with structural break.

Variable	**SC (Level)**		**SC (First Difference)**		**AC (Level)**		**AC((First Difference)**	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend	Intercept	Intercept & Trend
lnIND	2.924605 (0.99)	-0.411318 (0.99)	-8.705415*** (0.01)	-9.637547*** (0.01)	1.749726 (0.99)	-0.411318 (0.99)	-2.834909 (0.77)	-9.263182*** (0.01)
lnINF	-1.699854 (0.99)	-6.533478*** (0.01)	-9.991143*** (0.01)	-9.587890*** (0.01)	-1.344864 (0.99)	-6.189096*** (0.01)	-4.397800** (0.05)	-4.428554 (0.15)
lnTI	- 4.977507*** (0.01)	-6.742821*** (0.01)	-7.977580*** (0.01)	-8.652789*** (0.01)	- 4.977507*** (0.01)	-6.742821*** (0.01)	-2.200210 (0.96)	-8.652789*** (0.01)

*, ** and *** indicate statistical significant at the 10%, 5% and 1% level respectively.

The results obtained from the structural break unit root tests in the modified ADF also indicate that the order of integration of the variables are the mix of $I(0)$ and $I(1)$, but none of them is significant at $I(2)$. In the conclusion we can express that both the results of conventional unit root tests and structural break unit root tests fulfill the conditions to use the ARDL approach in this study.

5.2. Estimation of ARDL Model

According to the ARDL method, selection of the lag order of the variables is very important for the specification of the model. Akaike information criterion (AIC) has been used to select the appropriate lag length for the model in our study. In the survey, Lütkepohl (2006) expressed that AIC has superiority for small sample data compared to any lag length criterion. AIC presents efficient and consistent results as compared to final prediction error (FPE), Schwarz information criterion (SC) and Hannan–Quinn information criterion (HQ). The selected model for the equation is ARDL (2, 1, 4, 0). According to the result of AIC, the optimum lag lengths of the variables lnIND, lnINF and lnTI are: $\rho = 2$, $\rho 1 = 1$ and $\rho 2 = 4$ respectively.

5.3. Diagnostic Test of the Model

In order to check the stability and fitness of our model, we operated serial correlation (Q-Statistics and Breusch-Godfrey Serial Correlation LM tests), Normality (Jarque-Bera test) and Heteroscedasticity ('Breusch-Pagan-Godfrey' test) in this study.

Table-5. Diagnostic Test

Test	F test (Probability)	Observed R^2
Breusch-Godfrey Serial Correlation LM test	0.4681	0.3114
Breusch-Pagan-Godfrey Heteroskedasticity test	0.2975	0.2752
Jarque-Bera test	4.766049	0.092271
R^2	0.873712	
Adjusted R^2	0.821092	

The results obtained from the different diagnostic tests are provided in Table: 5. According to the table, the R^2 is 0.873712 and adjusted R^2 is 0.821092 of our model. The results of the analysis illustrate that more than 82% variations in the dependent variables are explained by the model and the rest by the error terms. The probability of F- statistics and observed R^2 tests indicate that our model passed all the tests regarding serial correlation, Normality and Heteroscedasticity tests. In this situation, we can conclude that this model is of good fit and passes all the diagnostic tests.

5.4. Bound Test

Since the basic tests of the model passed all the required diagnostics tests, we are going to turn to the next level of analysis which is called the bounds test for cointegration following Pesaran *et al.* (2001). They developed the critical values of the F-statistic for the asymptotic distribution.

Table-6. Bound test for cointegration

F Statistic	54.60602	
Number of Independent Variables – k	3	
Critical Values	Lower Bound	Upper Bound
1%	3.65	4.66
5%	2.79	3.67
10%	2.37	3.2

The result of ARDL bounds test revealed that model F-test is 54.60602. The value of the estimated F-statistic of our model has exceeded the upper bound at the 1% level of significance. It is apparent from the results that there is long-run relationship exists among our variables.

5.5. Long Run Dynamics

We have calculated the long-run equilibrium relationship between the variables using the ARDL model (2, 1, 4, 0). The result of the long run estimation is summarized in the table (7) below:

Table-7. Estimated long-run coefficients in ARDL

Variables	Coefficient	t- statistic	Probability
lnINF	0.9936***	51.9756	0.0000
lnTI	-0.1829***	-4.7252	0.0001
DUM01	0.0302	1.0528	0.3029
C	1.1886***	3.2323	0.0036

*, ** and *** indicate statistical significant at the 10%, 5% and 1% level respectively. **Source: Authors own calculation in Eviews.**

The results illustrate that the coefficients are significant for the variables technological innovation, infrastructure and Industrial growth. The obtained results from model indicate that infrastructure has a positive impact on the Industrial Growth in the long run which is confirmed by the sign and statistical significance of their coefficients. On the contrary, technological innovation has a negative impact on the Industrial Growth in the long run. Generally, it is believed that technological innovation can't be negative for economic growth. But for Bangladesh, it is found negative. The same result was documented in the study of Ishida (2015) for Japan and Lee *et al.* (2005) for Japan, Italy, and Spain. This finding is very much significant and important for a developing country like Bangladesh. The reasons of the impact of technological innovation being negative on Industrial Growth in the long run for Bangladesh are: 1. less Government investment in ICT sector; 2. less Government investment in R&D in the Industrial sector; 3. very low expenditure in university-based research and 4. misuse of Government expenditure in this sector for corruption.

About infrastructure – Growth nexus in the long run, our findings is similar to the result of Sawada (2012); Mahmud and Sawada (2015); Achour and Belloumi (2016); Chingoiro and Mbulawa (2016); Raychaudhuri and De (2016); Sawada *et al.* (2017); Udah and Bassey (2017); Khandker and Samad (2018). However, it is in contrast to the results of Holtz-Eakin and Schwartz (1994); Bougheas *et al.* (2000); Songco (2002); German-Soto *et al.* (2017). In the context of Technology- Growth nexus, our results is partially supported by Lee *et al.* (2005); Ishida (2015); McCartney (2017) and it is against the findings of Ahmed and Ridzuan (2013); Sohag *et al.* (2015); Shahbaz *et al.* (2016); Kumar *et al.* (2017).

5.6. Short Run Analysis

After explaining the long run relationship of the variables, now we move to elaborate the short-run causality in ARDL model (2, 1, 4, 0) in the table (8) below:

Table-8. Short run estimation from ECM.

Variable	Coefficient	Standard Error	t-statistic	Probability
D(lnIND(-1))	0.1147	0.0919	1.2483	0.2239
D(lnINF)	0.6160***	0.1080	5.6993	0.0000
D(lnTI)	-0.0043	0.0123	-0.3526	0.7274
D(lnTI(-1))	0.0346**	0.0124	2.7842	0.0103
D(lnTI(-2))	-0.0167	0.0156	-1.0734	0.2938
D(lnTI(-3))	0.0407***	0.0122	3.3292	0.0028
D(DUM01)	0.0135	0.0134	1.0051	0.3248
CointEq(-1)	-0.4481***	0.0703	-6.3685	0.0000

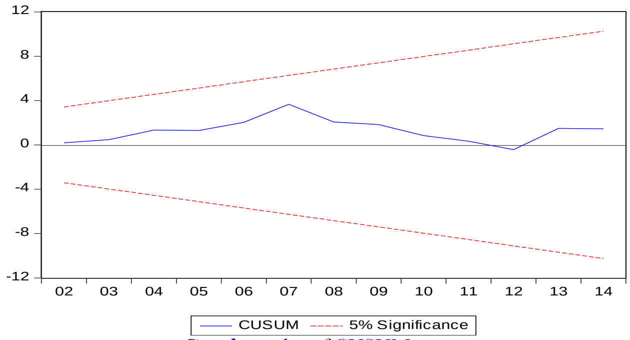
*, ** and *** indicate statistical significant at the 10%, 5% and 1% level respectively.

The results of the short run analysis reveal that short-run dynamics are also running so as the long-run relationships among the variables. The sign of lagged error correction term - CointEq(-1) has a negative and strong significant even at 1% level. This figure and sign represent that there exists a long-term relationship between the dependent variables and the regressors. In addition, the value of ECT coefficient is -0.4481 which signifies strong and a faster speed of adjustment to equilibrium. Thus nearly 44% of the disequilibrium converges back to the long-term equilibrium within one year. Both infrastructure and technological innovation have a positive and significant impact on Industrial Growth in the short-run which is confirmed by the sign and statistical significance of the coefficients. Both the results obtained from a long run and short run analysis reveal that technological innovation and infrastructure have substantial effect on Industrial growth.

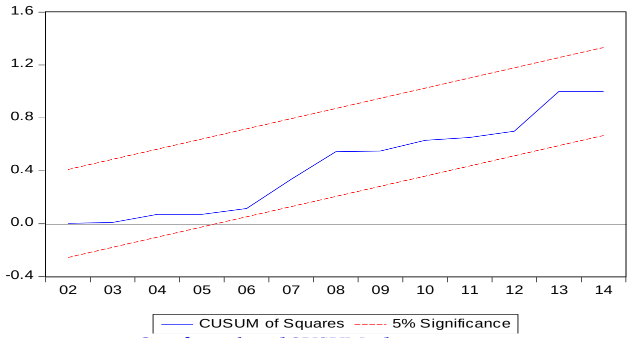
About infrastructure – Growth nexus in the short run, our findings are similar to the result of Achour and Belloumi (2016); Chingoiro and Mbulawa (2016); Udah and Bassey (2017). However, it is in contrast to the results of Evans and Karras (1994); Holtz-Eakin and Schwartz (1994); Songco (2002). In the context of Technology-Growth nexus in short run, our results is partially supported by Sohag *et al.* (2015); Shahbaz *et al.* (2016); Kumar *et al.* (2017) and it is against the findings of Ishida (2015); McCartney (2017).

5.7. Stability of the Model

In order to confirm the robustness of the long run dynamics and short-run results of our analysis, we have used the structural stability tests on the parameters based on the cumulative sum of recursive residuals (CUSUM) and the cumulative sum of recursive residuals of squares (CUSUMSQ) tests suggested by Pesaran and Pesaran (1997). Graph 1 and 2 are presented below:



Graph-1. plot of CUSUM test



Graph-2. plot of CUSUM of squares test

The graphical representations of CUSUM and CUSUMSQ statistics have been provided in Graph1 and 2. It is established in research that if the plots of the CUSUM and CUSUMSQ stay within the 5 percent critical bound, it would confirm the constancy of the parameter and stability of the model. The graphical representation of both the plots reveals that none of the straight lines (drawn at the 5% level) are crossed by CUSUM and CUSUMSQ. It means the plots of both the CUSUM and CUSUMSQ are within the boundaries and our model is stable.

5.8. Granger Causality Test

The bound tests in ARDL approach between our respective variables have explained the long-run relationships and short-run causality. Now, for the cross-check of our findings, we want to apply Granger causality test to determine the causality and directions between the variables. In this test, we want to confirm unilateral, bidirectional or no directional causality running among our variables. We examined the causal relationships between technological innovation, infrastructure and Industrial growth in Bangladesh within an augmented VECM model. The results obtained from the mentioned test have been presented in Table: 9.

Table-9. Granger Causality test.

Direction of Causality				
Variables	**lnIND**	**lnINF**	**lnTI**	
lnIND	---	4.15505***	6.93617***	Bi-directional
lnINF	3.37242**	----	5.88154**	Bi-directional
lnTI	0.98899	10.1034***	---	Uni- directional

*, ** and *** indicate statistical significant at the 10%, 5% and 1% level respectively. **Source: Authors own calculation in Eviews.**

The result obtained from the Granger causality test reveals the existence of a bi-directional causality running between Industrial growth and infrastructure, and between infrastructure and technological innovation. On the other hand, it also indicates a unidirectional causality running from Industrial growth to technological innovation. The findings of the Granger causality test supports the results obtained in the ARDL approach in our study.

The obtained results favor the findings of aforementioned studies of Chingoiro and Mbulawa (2016); Shahbaz *et al.* (2016); Kumar *et al.* (2017); Udah and Bassey (2017).

6. CONCLUSION AND POLICY IMPLICATION

In this study we investigated the empirical cointegration, long and short-run dynamics and causal relationships among technological innovation, infrastructure and Industrial development for Bangladesh over the period of 1974–2016. We have applied the ARDL Bounds Testing approach to determine the cointegration, Unrestricted Error Correction Model (UECM) for long and short-run dynamics and Granger Causality test in the VECM framework. The ARDL bounds tests, as well as additional cross-checking test, confirmed long run as well as short-run cointegration between the three variables in Bangladesh. The obtained results expressed that infrastructure has a positive impact on the industrial growth but technological innovation has a negative impact on industrial growth in the long run. In the short run, infrastructure and technological innovation both have a positive and significant impact on Industrial Growth. Granger causality test reveals the existence of a bi-directional causality running between Industrial growth and infrastructure; and between infrastructure and technological innovation. On the other hand, unidirectional causality is running from industrial growth to technological innovation. The findings of the Granger causality test supports the results obtained in the ARDL approach in our study. The results obtained from this empirical analysis have an important policy implication for a developing country like Bangladesh as well as other developing countries.

The empirical findings obtained from our experiment reveals that technological innovation is not playing so expected role in Industrial growth and infrastructure in Bangladesh as it is desired and should play. Since Bangladesh ranked 120th and 114th in technological readiness and innovation respectively out of 137 countries, Bangladesh remains far behind from the world standard of technological progress. Taking all these things into consideration, Bangladesh Government should review the existing technological innovation policy and should take necessary steps to change or improve this policy. An updated and improved technological innovation policy will not only reduce the production cost but also increase the Industrial growth of the country.

One of the major impacts of technology would be on the environment. Now industries like leather, chemical and shipbuilding are destroying the environment, but the inclusion of green and clean technology in these harmful industries would improve the environmental quality of the country as a whole. In spite of importing new technology, adoption and absorption are difficult and expensive for a developing country like Bangladesh; it has a longitudinal effect on the economy in future. So Government of Bangladesh should formulate the technological innovation policy which will increase the industrial growth and economic growth of the country as a whole. Government investment in R&D in the industrial sector (BD's ranking 113 out of 137 countries) and university-based research (BD's ranking 130 out of 137 countries) could improve this situation like China.

Secondly, in case of infrastructure, Bangladesh's position is 111th out of 137 countries. In line with technological innovation, infrastructure is also lying far behind not only in the world standard but also in the South Asian region. So there is enormous room for the infrastructural development of Bangladesh. Though Bangladesh is implementing three large mega infrastructural projects, she should keep it up and also need to take necessary policy and steps to improve more in this sector. It is observed that country like China and India have achieved tremendous success in overall economic growth by planned development in the infrastructure sector, Bangladesh can also achieve it. Another important matter about infrastructure is the inclusion of green infrastructural policy. Bangladesh has built the Jamuna Bridge over its second-biggest mighty river the Jamuna. This bridge has increased the economic activity and life standard of the people of the north-west region of the country; on the other hand, it has destructed the ecological balance and biodiversity of thousand years of the river and adjacent areas. Now the river is almost dead. So government should take care of the ecological environment and biodiversity in implementing large mega infrastructural projects.

In conclusion, pro-industrial growth or pro-economic growth infrastructural and technological innovation policy would intensify the overall economic growth of the country, will attract the FDI, boost the local and international trade, and enlarge the stock market which will ensure the balanced and stable growth of the country.

In the same way, an adaptation of green and clean infrastructural and technological innovation policy would have a significant positive effect on pollutant based industries and unplanned urbanization process which will improve the environmental quality of the country. From the policy point of view, any single or individual policy action in any macroeconomic variable like technological innovation, infrastructure and Industrial development will not bring any successful result. Thus an integrated macro-variable policy will ensure the sustainable growth of a country like Bangladesh.

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REFERENCES

Achour, H. and M. Belloumi, 2016. Investigating the causal relationship between transport infrastructure, transport energy consumption and economic growth in Tunisia. Renewable and Sustainable Energy Reviews, 56: 988-998. *View at Google Scholar* | *View at Publisher*

Ahmed, E.M. and R. Ridzuan, 2013. The impact of ICT on East Asian economic growth: Panel estimation approach. Journal of the Knowledge Economy, 4(4): 540-555. *View at Google Scholar* | *View at Publisher*

Ameer, A. and K. Munir, 2016. Effect of economic growth, trade openness, urbanization, and technology on environment of selected Asian Countries. MPRA Paper No. 7457. Retrieved from https://mpra.ub.uni-muenchen.de/74571/.

Ang, J.B., 2009. CO 2 emissions, research and technology transfer in China. Ecological Economics, 68(10): 2658-2665. *View at Google Scholar* | *View at Publisher*

Aschauer, D.A., 1989. Is public expenditure productive? Journal of Monetary Economics, 23(2): 177-200. *View at Google Scholar*

Atzeni, G.E. and O.A. Carboni, 2006. ICT productivity and firm propensity to innovative investment: Evidence from Italian microdata. Information Economics and Policy, 18(2): 139-156. *View at Google Scholar* | *View at Publisher*

Ayeche, M.B., M. Barhoumi and M.A. Hammas, 2016. Causal linkage between economic growth, financial development, trade openness and CO2 emissions in European Countries. American Journal of Environmental Engineering, 6(4): 110-122. *View at Google Scholar*

Bai, J. and P. Perron, 2003. Computation and analysis of multiple structural change models. Journal of Applied Econometrics, 18(1): 1-22. *View at Google Scholar* | *View at Publisher*

Barnes, D.F. and H.P. Binswanger, 1986. Impact of rural electrification and infrastructure on agricultural changes, 1966-1980. Economic and Political Weekly, 21(1): 26-34. *View at Google Scholar*

Barros, C.P., L.A. Gil-Alana and J.E. Payne, 2011. An analysis of oil production by OPEC countries: Persistence, breaks, and outliers. Energy Policy, 39(1): 442-453. *View at Google Scholar* | *View at Publisher*

Binswanger, H.P., S.R. Khandker and M.R. Rosenzweig, 1989. The impact of infrastructure and financial institutions on agricultural output and investment in India. Latin America and Caribbean Country Department II, World Bank.

Bougheas, S., P.O. Demetriades and T.P. Mamuneas, 2000. Infrastructure, specialization, and economic growth. Canadian Journal of Economics/Revue Canadienne d'Economique, 33(2): 506-522. *View at Google Scholar* | *View at Publisher*

Brenneman, A. and M. Kerf, 2002. Infrastructure & poverty linkages. A literature review. Washington, DC: The World Bank.

Brock, W.A. and M.S. Taylor, 2010. The green Solow model. Journal of Economic Growth, 15(2): 127-153. *View at Google Scholar* | *View at Publisher*

Brown, R.L., J. Durbin and J.M. Evans, 1975. Techniques for testing the constancy of regression relationships over time. Journal of the Royal Statistical Society. Series B (Methodological), 37(2): 149-192. *View at Google Scholar*

Brynjolfsson, E. and L.M. Hitt, 2003. Computing productivity: Firm-level evidence. Review of Economics and Statistics, 85(4): 793-808. *View at Google Scholar*

Calderón, C. and L. Servén, 2004. The effects of infrastructure development on growth and income distribution. World Bank Publications, 270. Retrieved from http://www.bcentral.cl/eng/stdpub/studies/workingpaper.

Castellacci, F. and J.M. Natera, 2013. The dynamics of national innovation systems: A panel cointegration analysis of the coevolution between innovative capability and absorptive capacity. Research Policy, 42(3): 579-594. View at Google Scholar | View at Publisher

Cederholm, H. and P. Zhong, 2017. The effects of financial openness on innovation: An empirical study. Sweden: Lund University, Lund.

Chavula, H.K. and A. Chekol, 2013. ICT policy development process in Africa. Publisher: IGI Global. DOI 10.4018/978-1-4666-3607-1.ch017.

Chester, M.V., J. Sperling, E. Stokes, B. Allenby, K. Kockelman, C. Kennedy, L.A. Baker, J. Keirstead and C.T. Hendrickson, 2014. Positioning infrastructure and technologies for low-carbon urbanization. Earth's Future, 2(10): 533-547. View at Google Scholar | View at Publisher

Chingoiro, S. and S. Mbulawa, 2016. Economic growth and infrastructure expenditure in Kenya: A Granger-causality approach. International Journal of Social Science Studies, 4: 1. View at Google Scholar | View at Publisher

Day, R.H. and G. Zou, 1994. Infrastructure, restricted factor substitution and economic growth. Journal of Economic Behavior & Organization, 23(2): 149-166. View at Google Scholar | View at Publisher

Destek, M.A., E. Balli and M. Manga, 2016. The relationship between CO2 emission, energy consumption, urbanization and trade openness for selected CEECs. Research in World Economy, 7(1): 52-58. View at Google Scholar | View at Publisher

Dethier, J.J., M. Hirn and S. Straub, 2010. Explaining enterprise performance in developing countries with business climate survey data. World Bank Research Observer, 26(2): 258-309. View at Google Scholar | View at Publisher

Dollar, D., M. Hallward-Driemeier and T. Mengistae, 2005. Investment climate and firm performance in developing economies. Economic Development and Cultural Change, 54(1): 1-31. View at Google Scholar | View at Publisher

Easterly, W. and S. Rebelo, 1993. Fiscal policy and economic growth. Journal of Monetary Economics, 32(3): 417-458. View at Google Scholar

Evans, P. and G. Karras, 1994. Are government activities productive? Evidence from a panel of US states. Review of Economics and Statistics, 76(1): 1-11. View at Google Scholar | View at Publisher

Fabiani, S., F. Schivardi and S. Trento, 2005. ICT adoption in Italian manufacturing: Firm-level evidence. Industrial and Corporate Change, 14(2): 225-249. View at Google Scholar | View at Publisher

Fedderke, J.W. and Ž. Bogetić, 2009. Infrastructure and growth in South Africa: Direct and indirect productivity impacts of 19 infrastructure measures. World Development, 37(9): 1522-1539. View at Publisher

Fedderke, J.W., P. Perkins and J.M. Luiz, 2006. Infrastructural investment in long-run economic growth: South Africa 1875–2001. World Development, 34(6): 1037-1059. View at Google Scholar | View at Publisher

Ferreira, P.C. and J.V. Issler, 1995. Growth, increasing returns, and public infrastructure: Time series evidence. Rio De Janerio, Brazil.

Fleisher, B., H. Li and M.Q. Zhao, 2010. Human capital, economic growth, and regional inequality in China. Journal of Development Economics, 92(2): 215-231. View at Google Scholar | View at Publisher

Garbacz, C. and J.H.G. Thompson, 2007. Demand for telecommunication services in developing countries. Telecommunications Policy, 31(5): 276-289. View at Google Scholar | View at Publisher

Garmendia, C.B., A. Estache and N. Shafik, 2004. Infrastructure services in developing countries: Access. Quality, Costs and Policy Reform, Washington: World Bank Working Paper, No. 3468.

German-Soto, V., F.L. Gutierrez and B.H. Barajas, 2017. An analysis of the relationship between infrastructure investment and economic growth in Mexican urban areas, 1985-2008. Economics Bulletin, 37(4): 2422-2433. View at Google Scholar

Ghosh, B. and P. De, 2005. Investigating the linkage between infrastructure and regional development in India: Era of planning to globalisation. Journal of Asian Economics, 15(6): 1023-1050. View at Google Scholar | View at Publisher

Ghosh, S.C., H. Rahman and A. Rana, 2010. Revisiting Jamuna bridge resettlement areas: Exploring livelihood status of the affected people. Dhaka: BRAC University.

Gramlich, E.M., 1994. Infrastructure investment: A review essay. Journal of Economic Literature, 32(3): 1176-1196. *View at Google Scholar*

Granger, C.W., 1969. Investigating causal relations by econometric models and cross-spectral methods. Econometrica: Journal of the Econometric Society, 37(3): 424-438. *View at Google Scholar | View at Publisher*

Group, W.B.I.E., 2008. The welfare impact of rural electrification: A reassessment of the costs and benefits; an IEG impact evaluation. World Bank Publications. World Bank.

Gruber, H. and P. Koutroumpis, 2010. Mobile communications: Diffusion facts and prospects. Communications & Strategies, 77, 1st Q: 133. Retrieved from www.comstrat.org.

Hardy, A.P., 1980. The role of the telephone in economic development. Telecommunications Policy, 4(4): 278-286. *View at Google Scholar | View at Publisher*

Hogan, L. and R. McNamee, n.d. Industry and infrastructure. Chapter 08, Economic Survey 2017-18: 120-150.

Holtz-Eakin, D. and A.E. Schwartz, 1994. Infrastructure in a structural model of economic growth. National Bureau of Economic Research. NBER Working Paper #4824, August 1994.

Hu, Q., 2005. Evaluating the impact of IT investments on productivity: A causal analysis at industry level. International Journal of Information Management, 25(1): 39-53. *View at Google Scholar | View at Publisher*

Hulten, C.R. and A. Isaksson, 2007. Why development levels differ: The sources of differential economic growth in a panel of high and low income countries. National Bureau of Economic Research.

Hulten, C.R. and R.M. Schwab, 1991. Public capital formation and the growth of regional manufacturing industries. National Tax Journal, 44(4): 121-134.

Ishida, H., 2015. The effect of ICT development on economic growth and energy consumption in Japan. Telematics and Informatics, 32(1): 79-88. *View at Google Scholar | View at Publisher*

Jamel, L. and S. Maktouf, 2017. The nexus between economic growth, financial development, trade openness, and CO2 emissions in European countries. Cogent Economics & Finance, 5(1): 1341456. *View at Google Scholar | View at Publisher*

Kahia, M., M.S.B. Aïssa and L. Charfeddine, 2016. Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs). Energy, 116: 102-115. *View at Google Scholar | View at Publisher*

Kahia, M., M.S.B. Aïssa and C. Lanouar, 2017. Renewable and non-renewable energy use-economic growth nexus: The case of MENA net oil importing countries. Renewable and Sustainable Energy Reviews, 71: 127-140. *View at Google Scholar | View at Publisher*

Kang, Y.Q., T. Zhao and Y.Y. Yang, 2016. Environmental Kuznets curve for CO2 emissions in China: A spatial panel data approach. Ecological Indicators, 63: 231-239. *View at Google Scholar | View at Publisher*

Khandker, S., Z. Bakht and G. Koolwal, 2006. The poverty impact of rural roads: Evidence from Bangladesh [Policy Research Working Paper Series]. Tech. Rep.). The World Bank.

Khandker, S. and G. Koolwal, 2006. Are pro-growth policies pro-poor? Mimeograph. Washington, DC: World Bank.

Khandker, S.R., Z. Bakht and G.B. Koolwal, 2009. The poverty impact of rural roads: Evidence from Bangladesh. Economic Development and Cultural Change, 57(4): 685-722. *View at Google Scholar | View at Publisher*

Khandker, S.R. and H.A. Samad, 2016. Transformation of rural Bangladesh: Role of infrastructure and financial institutions.

Khandker, S.R. and H.A. Samad, 2018. Bangladesh's structural transformation: The role of infrastructure. Economic and Social Development of Bangladesh. Springer.

Koutroumpis, P., 2009. The economic impact of broadband on growth: A simultaneous approach. Telecommunications Policy, 33(9): 471-485. *View at Google Scholar | View at Publisher*

Kumar, R.R., P.J. Stauvermann and S.J.H. Shahzad, 2017. Can technology provide a glimmer of hope for economic growth in the midst of chaos? A case of Zimbabwe. Quality & Quantity, 51(2): 919-939. *View at Google Scholar | View at Publisher*

Lee, S.Y.T., R. Gholami and T.Y. Tong, 2005. Time series analysis in the assessment of ICT impact at the aggregate level–lessons and implications for the new economy. Information & Management, 42(7): 1009-1022. View at Google Scholar | View at Publisher

Lütkepohl, H., 2006. Structural vector autoregressive analysis for cointegrated variables. Allgemeines Statistisches Archiv, 90(1): 75-88. View at Google Scholar | View at Publisher

Madden, G. and S.J. Savage, 1998. CEE telecommunications investment and economic growth. Information Economics and Policy, 10(2): 173-195. View at Google Scholar | View at Publisher

Mahmud, M. and Y. Sawada, 2015. Infrastructure and well-being: Employment effects of Jamuna Bridge in Bangladesh. CIRJE Discussion Paper, No. (986).

McCartney, M., 2017. Bangladesh 2000-2017: Sustainable growth, technology and the irrelevance of productivity. Lahore Journal of Economics, 22: 183-198. View at Google Scholar

Nelson, C.R. and C.R. Plosser, 1982. Trends and random walks in macroeconmic time series: Some evidence and implications. Journal of Monetary Economics, 10(2): 139-162. View at Google Scholar | View at Publisher

O'Mahony, M. and M. Vecchi, 2005. Quantifying the impact of ICT capital on output growth: A heterogeneous dynamic panel approach. Economica, 72(288): 615-633. View at Google Scholar | View at Publisher

Okoh, A. and B. Ebi, 2013. Infrastructure investment, institutional quality, and economic growth in Nigeria: An interactive approach. European Journal of Humanities and Social Sciences, 26(1): 1343-1358. View at Google Scholar

Oulton, N., 2012. Long term implications of the ICT revolution: Applying the lessons of growth theory and growth accounting. Economic Modelling, 29(5): 1722-1736. View at Google Scholar | View at Publisher

Perron, P., 1989. The great crash, the oil price shock, and the unit root hypothesis. Econometrica: Journal of the Econometric Society, 57(6): 1361-1401. View at Google Scholar | View at Publisher

Pesaran, M.H. and B. Pesaran, 1997. Working with microfit 4.0: Interactive econometric analysis; windows version. Oxford University Press.

Pesaran, M.H. and B. Pesaran, 1997. Working with microfit 4.0: Interactive econometric analysis;[windows version]. Oxford University Press.

Pesaran, M.H. and Y. Shin, 1998. An autoregressive distributed-lag modelling approach to cointegration analysis. Econometric Society Monographs, 31: 371-413. View at Google Scholar

Pesaran, M.H., Y. Shin and R.J. Smith, 2001. Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16(3): 289-326. View at Google Scholar | View at Publisher

Pradhan, R.P. and T.P. Bagchi, 2013. Effect of transportation infrastructure on economic growth in India: The VECM approach. Research in Transportation Economics, 38(1): 139-148. View at Google Scholar | View at Publisher

Rahman, M.M., 2017. Do population density, economic growth, energy use and exports adversely affect environmental quality in Asian populous countries? Renewable and Sustainable Energy Reviews, 77: 506-514. View at Google Scholar | View at Publisher

Rahman, M.M. and M.A. Kashem, 2017. Carbon emissions, energy consumption and industrial growth in Bangladesh: Empirical evidence from ARDL cointegration and Granger causality analysis. Energy Policy, 110: 600-608. View at Google Scholar | View at Publisher

Ramanathan, R., 2001. The long-run behaviour of transport performance in India: A cointegration approach. Transportation Research Part A: Policy and Practice, 35(4): 309-320. View at Google Scholar | View at Publisher

Raychaudhuri, A., 2004. Lessons from the land reform movement in West Bengal, India.The World Bank Publication.

Raychaudhuri, A. and P. De, 2016. Trade, infrastructure and income inequality in selected Asian countries: An empirical analysis. In International Trade and International Finance. New Delhi: Springer.pp: 257-278.

Report, M.C., 2017. New solutions for global infrastructure Singapore 2017 Summit. Mackinsay Company Report, Publisher: Mckinsay and Company

Roland-Holst, D., 2009. Infrastructure as a catalyst for regional integration, growth, and economic convergence: Scenario analysis for Asia. From Growth to Convergence. Springer. pp: 108-149.

Romer, P.M., 1990. Endogenous technological change. Journal of Political Economy, 98(5): S71-S102.

Samimi, R., 1995. Road transport energy demand in Australia a cointegration approach. Energy Economics, 17(4): 329-339. *View at Google Scholar* | *View at Publisher*

Sarkar, P., A. Anjum and E.A. Khan, 2017. Overview of major industries in Bangladesh. Journal of Chemical Engineering, 30(1): 51-58. *View at Google Scholar* | *View at Publisher*

Sassi, S. and M. Goaied, 2013. Financial development, ICT diffusion and economic growth: Lessons from MENA region. Telecommunications Policy, 37(4-5): 252-261. *View at Google Scholar* | *View at Publisher*

Sawada, Y., 2012. Infrastructure, social cohesion, and jobs in development: A note on the WDR Bangladesh case study. Mimeo. Tokyo: Japan International Cooperation Agency JICA-RI.

Sawada, Y., M. Mahmud and N. Kitano, 2017. Economic and social development of Bangladesh: Miracle and challenges. Springer.

Schwab, K., 2017. The global competitiveness report 2017–2018. Ginevra: World Economic Forum.

Seo, H.J., Y.S. Lee and J.H. Oh, 2009. Does ICT investment widen the growth gap? Telecommunications Policy, 33(8): 422-431. *View at Google Scholar* | *View at Publisher*

Shahbaz, M., 2012. Does trade openness affect long run growth? Cointegration, causality and forecast error variance decomposition tests for Pakistan. Economic Modelling, 29(6): 2325-2339. *View at Google Scholar* | *View at Publisher*

Shahbaz, M., Q.M.A. Hye, A.K. Tiwari and N.C. Leitão, 2013. Economic growth, energy consumption, financial development, international trade and CO2 emissions in Indonesia. Renewable and Sustainable Energy Reviews, 25(C): 109-121. *View at Google Scholar* | *View at Publisher*

Shahbaz, M., I.U. Rehman, R. Sbia and H. Hamdi, 2016. The role of information communication technology and economic growth in recent electricity demand: Fresh evidence from combine cointegration approach in UAE. Journal of the Knowledge Economy, 7(3): 797-818. *View at Google Scholar* | *View at Publisher*

Shahbaz, M., T.H. Van Hoang, M.K. Mahalik and D. Roubaud, 2017. Energy consumption, financial development and economic growth in India: New evidence from a nonlinear and asymmetric analysis. Energy Economics, 63: 199-212. *View at Google Scholar* | *View at Publisher*

Siddique, H.M.A. and M.T. Majeed, 2015. Energy consumption, economic growth, trade and financial development nexus in South Asia: 658-682.

Sohag, K., R.A. Begum, S.M.S. Abdullah and M. Jaafar, 2015. Dynamics of energy use, technological innovation, economic growth and trade openness in Malaysia. Energy, 90: 1497-1507. *View at Google Scholar* | *View at Publisher*

Solow, R.M., 1956. A contribution to the theory of economic growth. Quarterly Journal of Economics, 70(1): 65-94. *View at Google Scholar*

Songco, J.A., 2002. Do rural infrastructure investments benefit the poor?: Evaluating linkages: A global view, a focus on Vietnam. World Bank Publications.

Stiroh, K.J., 2002. Information technology and the US productivity revival: What do the industry data say? American Economic Review, 92(5): 1559-1576. *View at Google Scholar* | *View at Publisher*

Tang, C.F. and E.C. Tan, 2013. Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. Applied Energy, 104: 297-305. *View at Google Scholar* | *View at Publisher*

TGE, 2018. Bangladesh: Industry value added.

The Global Economy, 2018. Bangladesh: Industry value added. Retrieved from https://www.theglobaleconomy.com/Bangladesh /industry_ value_added/%20%5b/ [Accessed 2018/05/12].

Udah, E. and E. Bassey, 2017. Infrastructure, human capital and Industrialization in Nigeria. Nile Journal of Business and Economics, 3(6): 58-78. *View at Google Scholar* | *View at Publisher*

Vu, K.M., 2011. ICT as a source of economic growth in the information age: Empirical evidence from the 1996–2005 period. Telecommunications Policy, 35(4): 357-372. *View at Google Scholar* | *View at Publisher*

Vu, K.M., 2013. Information and communication technology (ICT) and Singapore's economic growth. Information Economics and Policy, 25(4): 284-300. View at Google Scholar | View at Publisher

Were, M., 2015. Differential effects of trade on economic growth and investment: A cross-country empirical investigation. Journal of African Trade, 2(1-2): 71-85. View at Google Scholar | View at Publisher

World Bank, 2017. Bangladesh development update, September 2017: Towards more, better, and inclusive jobs. Dhaka: The World Bank.

Appendix:

Definition of three variables:

1. Infrastructure

The term 'infrastructure' indicates economic infrastructure. Economic infrastructure can be categorized into three types: (1) public utilities that involve power, telecommunications, piped water supply, sanitation and sewerage, solid waste collection and disposal, and piped gas; (2) public works that include roads, bridges, major dam and canal works for irrigation and drainage; and (3) other transport facilities that include urban and inter-urban railways, urban transport, ports and waterways, and airports. A bridge construction project in a rural area can change the surrounding rural community and may gradually push the entire area toward modern settings. Thus, investment in infrastructure can be one of the prominent catalysts of economic development.

2. Gross Capital Formation

According to the definition of WDI 'Gross Capital Formation' (formerly gross domestic investment) consists of outlays on additions to the fixed assets of the economy plus net changes in the level of inventories. Fixed assets include land improvements (fences, ditches, drains, and so on); plant, machinery, and equipment purchases; and the construction of roads, railways, and the like, including schools, offices, hospitals, private residential dwellings, and commercial as well as industrial buildings. It is mentioned that Inventories are stocks of goods held by firms to meet temporary or unexpected fluctuations in production or sales, and "work in progress." According to the 1993 SNA, net acquisitions of valuables are also taken in the capital formation.

3. Industrial Value Added

According to the definition of WDI 'Industry value added' consists of the value added in mining, manufacturing, construction, electricity, water, and gas. The computation of value added is the net output of a sector after adding up all outputs and subtracting intermediate inputs. It has been calculated without making deductions for depreciation of fabricated assets or depletion and degradation of natural resources. It has been mentioned that the origin of value added is determined by the International Standard Industrial Classification (ISIC), revision 3. Data that is presented are in constant 2010 U.S. dollars.