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Technological Innovation, Trade Openness, CO_2 Emission and Economic Growth: Comparative Analysis between China and India

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ABSTRACT

China and India are the two biggest transitional and developing economies of Asia but remains in the two distinct separate stages of structural change, technological innovation, trade, energy use, economic growth as well as different in culture and religious beliefs. The aim of this study is to examine and compare the long and short-run relationships between Technological innovation, Trade openness, CO_2 emission and Economic growth of China and India over the period of 1974-2016. We have utilized the ARDL Bounds Test methodology and Toda-Yamamoto Granger Causality test. The obtained results revealed that Technological innovation, Trade openness and CO_2 emission have a significant positive impact on Economic growth in the long-run but mixed effect in the short-run in China. For India, On the other hand, Trade openness and CO_2 emission have a significant positive impact in the long-run but CO_2 emission has a negative impact in the short-run on Economic growth. Technological innovation is not significant in the long-run and both Technological innovation and Trade openness are not significant on Economic growth for India in the short-run. The Toda-Yamamoto Granger causality test reveals that bi-directional causality is running between Economic growth and Trade openness, between Technological innovation and CO_2 emissions as well as a unidirectional causality is running from Technological innovation and CO_2 emissions to Trade openness for China. On the other hand, our obtained results express that there is a unidirectional causality running from Economic growth, Technological innovation and Trade openness to CO_2 emissions as well as from Technological innovation to Trade openness for India. The results obtained from this empirical analysis have an important policy implication for China and India.

Keywords: Technological Innovation, Trade Openness, CO_2 Emission, Economic Growth, ARDL, Toda-Yamamoto Granger Causality, China and India

JEL Classifications: F43, O11, O33, O57, Q43

1. INTRODUCTION

China and India are the two major transitional and emerging economies of Asia but remains in the two distinct separate stages of structural change, technological innovation, trade, energy use, economic growth as well as different in culture and religious beliefs. Both the countries are large having one-third the population of the world and belongs the nuclear power. China is a permanent member of the UN Security Council with "veto" power and India is a big power in South and South-East Asia. The political system of these two countries is different: India is a democratic country and China is a communist country. So these two countries are playing very important and crucial role in the politics and economy not only in this region but also in the world. From 1989 to 2018 China has achieved 9.61% and from 1951 until 2018 India has realized 6.15% economic growth (Economics, 2018). Both the countries have made dramatic progress not only in the economic sector but also in the poverty alleviation. Especially, the Chinese economic growth is a miracle to the scholars, academicians and International agencies such as the World Bank and IMF.

According to the report of Global Competitiveness Index 2017-2018, published by the World Economic Forum, covering 137 countries, China lies in Stage-2 and India is in Stage-1 of the level of development (Schwab). It refers that India is in the primary stage and China is in the second stage of overall development. The population of China and India is 1382.7 million and 1309.3 million (April-2017) respectively; which refers to about one-third population of the world live in this two countries. GDP per capita of China is $8118.3 and of India is $1723.3, means China's GDP per capita is 4.71 times than that of India. So India is far behind of China in the case of economic development. In accordance with the economic structure, China had been a manufacturing-based economy and India was a more balanced mix of manufacturing and services based economy in 2015 (Schwab).

In 2017, the total primary energy consumption in China was 3132.2 Million tonnes oil equivalent (Mtoe) which was 23.2% of the world total, making China the principal energy consumer in the world. This year China emitted 9232.6 million tones CO_2 accounting for 27.6% of the world total, which is also the largest in the world. On the other hand, India has consumed 753.7 Mtoe total primary energy. It was 5.6% of the world total in 2017. In the case of CO_2 emissions, India emitted 2344.2 Million tonnes of CO_2, which contributed 7% of the world total. So the total CO_2 emissions from China and India were 34.6% in 2017 which contributed more than one-third of the total world (B. P. Report, June, 2018).

In accordance with the overall Global Competitiveness Index, the ranking of China and India is 27 and 40 out of 137 countries (Schwab). The ranking in the quality of Infrastructure, Macroeconomic environment and financial market development of China and India are 46, 66 and 17 and 80, 48 and 42 respectively. It indicates that India has to go a long way to catch up with China in these sectors. The ranking of Technological readiness and Innovation are 73 and 107 and 28 and 29 of China and India respectively. This data reveals that India is competing with China in the Innovation sector but far away in the Technological readiness. The ranking of China and India in the Market size and Goods market efficiency are 1 and 3, and 46 and 56 respectively which is very much remarkable. China and India stand first and third in the Market size of the world which reveals that about 30% of world consumers live in these two countries (Schwab).

The same report revealed that the overall Chinese ranking has upgraded one rank (27th position) which refers to the steady situation of its economy and it has gained improvements in overall competitiveness score (Schwab). It has been documented in the report that China has achieved development in all parameters except in the infrastructure and macroeconomic environment since previous year (2016-2017). Government budget deficit was the reason behind the decline of infrastructure and the ranking of the infrastructure pillar decreases because of the trustworthiness of electricity supply recognized by the business community and the deteriorate in the standard of port infrastructure. China achieved the major gains in technological readiness due to higher ICT penetration and an increase in the Foreign Direct Investment (FDI). FDI is bringing new technologies to China. It was also commented that though China has made remarkable progress in technological readiness, more development of this sector would promote the growth of rising digital industries and generate the necessary situation to begin new ones. They also observed remarkable development in the goods market competence pillar because of the moderate cutback in the number of processes for starting a business (Schwab).

In the case of India, it was revealed in the report that India (40th) is improving in overall economic development for the last two consecutive years. It has improved in most of the pillars of competitiveness, especially in infrastructure, higher education and training, and technological readiness. The reason behind it is the public investments in these sectors recently. India has also made remarkable progress in ICT indicators, particularly mobile phone and broadband subscriptions, Internet bandwidth per user, and Internet access in schools. The report also commented that the quality of institutions has increased for public spending (Schwab).

The recent publication of IMF revealed that resurgent net exports and strong private consumption supported mostly in the growth of China and India last year in 2017 whereas investment growth slowed down. The report also projected that growth will be decreased to 6.6% in 2018 from 6.9% in 2017 to 6.4% in 2019 in China. In recent years, China has joined the top five leaders of R & D and the stock of international patents, and the optical equipment and electrical sector have also improved. China's contribution to the growth of the technology sector might create positive spillovers to the conventional technology leaders (I. Report, April, 2018).

After a remarkable discussion in the economic data of China and India, let's have a look in the related literature. In an empirical study, Ameer and Munir (2016) revealed that it is extremely surprising to observe how economic growth, trade openness, technology, urbanization, and environment are functioning simultaneously as well as against one another at the similar period. They commented that technological advancement has reduced the cost of transportation and communication. Technology is bringing the world closer and facilitating to resolve the predicaments (Kang et al., 2016). It is documented that environmental degradation expands with economic development but reduce with technological progress. The researcher Were (2015) revealed that Globalization is characterized not only rigorous trade openness and trade incorporation but also has been related to the technological uprising.

Another important macroeconomic variable is trade and there is a agreement that trade accelerates the economic growth. The researcher Yanikkaya (2003) revealed that trade boosts economic activities in the course of two channels. First, is the cumulative scale effect which is realized from trade openness. It is mentioned that trade openness increases in firms' size, which reduces the average costs of production by increasing the output of the firms. The second channel is technology transfer which comes from knowledge spill-over. It improves the communications infrastructure to facilitate greater trade activities.

Though Trade and Technology are playing a strong positive role in the economic growth they are increasing the use of energy as well. In the case of China and India, rapid economic growth has been followed by growing energy consumption and CO_2 emissions. The burning of fossil fuels such as oil, coal, and gas emit CO_2 and CO_2 emissions contribute significantly to the climate change which is the cause of global warming. So there is a strong relationship between Technological innovation, Trade openness, CO_2 emission and Economic growth.

There are a good number of research works which examined the impact of different variables on China and India. Bosworth and Collins (2008) examined the patterns of economic growth; Qureshi and Wan (2008) checked export performances and specialization patterns; Bansal (2011) compared the growth of e-commerce and internet development; Agrawal and Khan (2011) documented the role of FDI on GDP; Lema and Lema (2012) examined technology transfer; Sun et al. (2012) documented the role of MNEs; Nguyen et al. (2017) showed the impact of investment on carbon emissions, energy consumption, and income; Adhikari and Ganguly (2017) explained comparative green industrial policies; Pradhan et al. (2017) examined carbon prices; Wolde-Rufael and Idowu (2017) showed income inequality and CO_2 emissions; Sun et al. (2018) compared the manufacturing trade and the total energy use; Shahbaz et al. (2018) studied the effect of urbanization, industrialization and service sector growth on financial development; Bharadwaj (2018) investigated the technical aspects of green technologies of both the countries; etc.

There is a large and increasing 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 (Ahmed and Ridzuan, 2013; Brynjolfsson and Hitt, 2003; Chester et al., 2014; Fabiani et al., 2005; Garbacz and Thompson Jr, 2007; Gruber and Koutroumpis, 2010; Hardy, 1980; Koutroumpis, 2009; Kumar et al., 2017; Madden and Savage, 1998; O'Mahony and Vecchi, 2005; Sarkar et al., 2017; Sassi and Goaied, 2013; Shahbaz et al., 2016; Sohag et al., 2015; Stiroh, 2002; Vu, 2011) revealed that different proxies of technology like technological innovation, ICT, broadband connection, telecommunications, mobile telecommunications, mobile cellular technology, financial openness, patents have a positive effect on economic growth.

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

Numerous studies have been conducted on the relationships of CO_2 emission and Economic growth. Grossman and Krueger (1991) and Selden and Song (1994) developed the EKC hypothesis which illustrates that economic growth and environmental degradation (measured by CO_2 emission) is inverted-U shaped and non-linear. It refers that economic growth is leading to a continuing degradation of the environment but after a definite stage of economic growth, it starts to improve again. The same result were found in the study of (Akpan and Akpan, 2012; Al-Mulali and Ozturk, 2015; Charfeddine and Khediri, 2016; Kais and Sami, 2016; Lean and Smyth, 2010; Li et al., 2016; Martínez-Zarzoso and Maruotti, 2011; Nasir and Rehman, 2011; Saboori et al., 2012; Shahbaz et al., 2014; Shahbaz et al., 2012; Tamazian and Rao, 2010; Wang et al., 2016).

Different proxies of economic growth increases CO_2 emissions have been documented in many studies like (Chang, 2010; Chebbi, 2010; Halicioglu, 2009; Jamel and Derbali, 2016; Shiyi, 2009; Tamazian et al., 2009; Zhang and Cheng, 2009).

Some of the researchers documented the mixed or negative impact of economic growth on CO_2 emissions (Chandran and Tang, 2013; Farhani and Ozturk, 2015; Hossain, 2012; Liu et al., 2007; Sharma, 2011).

There are a large number of studies which have investigated the relationships of trade openness and Economic growth and most of the studies found the positive impact of trade openness on economic growth (Das and Paul, 2011; Dollar, 1992; Edwards, 1998; Iyke, 2017; Khalid and Ahmad, (2017); Mitra, 2016; Muhammad et al., 2012; Nannicini and Billmeier, 2011; Pernia and Quising, 2003; Sachs et al., 1995; Shahbaz, 2012; Vamvakidis, 2002; Vogiatzoglou and Nguyen, 2016; Wacziarg and Welch, 2008; Yavari and Mohseni, 2012; Yusoff and Febrina, 2012).

Some study found the mixed or negative effect of trade openness on economic growth (Jawaid et al., 2011; Menyah et al., 2014; Musila and Yiheyis, 2015; Trejos and Barboza, 2015).

The objectives of our present study are as follows:

a. To analyze and compare the impact of three most important macroeconomic variables: Technological innovation, Trade openness and CO_2 emission on the Economic growth of China and India.
b. To analyze the form of the short-run and long-run relationships (no directional, Unidirectional or bidirectional/feedback) between Technological innovation, Trade openness, CO_2 emission and Economic growth on each other of the two countries.
c. To find out the policy implication for the Government of both the countries to formulate national technological policy, trade policy and energy policy to promote economic growth by policy synchronization at the national and international level.

Going through the existing literature, we observe that numerous researcher conducted lots of study on different variables utilizing different methods to compare China and India. But few types of research have been conducted about the impact of Technological innovation, Trade openness, CO_2 emission on Economic growth together for these two countries. So far as our findings, we have studied the relationships of these four variables for China and India for the 1st time. The major contributions of our study in the existing literature are: (I) It examined the short-run and long-run relationships among Technological innovation, Trade openness, CO_2 emission and Economic growth for the two largest emerging economy China and India for the period of 1974-2016 applying ARDL cointegration bound test and Toda- Yamamoto Granger Causality test in an augmented VAR framework with Zivot-Andrews structural break unit root test. (II) Most updated and longest time series data (1974-2016) from a highly reliable source - World Development Indicators (WDI) of the World Bank - have been used in this study, (III) we have included Technological innovation for the 1st time to study and compare the impact of it on the economic growth of these two countries and (IV) the obtained results of this study would provide policymakers of China and India to understand Technological innovation, Trade openness, CO_2 emission and Economic growth nexus as well as to formulate national technological policy, trade policy and energy policy to foster economic growth by policy coordination at the national and international level. For this reason, this research holds a great importance in the literature arena and will fill up the gap in the existing economic literature.

The rest of the part of this paper is designed in the following way: Section 2 documented the review of the past literature; Section 3 illustrates data and econometric model; Section 4 presents the estimation, findings, result analysis and discussion; at last (Section 5), we have compared the major findings and suggested some important policy implications of this study for both the countries.

2. LITERATURE REVIEW

There is a volume of studies on China and India but the number of empirical studies is countable. Several studies have analyzed the impact of Technological innovation, Trade openness and CO_2 emissions on the Economic growth of China and India separately. The results of these research works are mixed. In order to have a sound review of the past literature, we have discussed it in groups: First, the literatures which have studied on China and India; second, the relationship of technology and growth; third, relationship of CO_2 emission and growth; fourth, Trade openness and growth; and at last miscellaneous literatures related with our variables.

In the study of Bosworth and Collins (2008) revealed that China achieved tremendous economic growth in the industrial sector in its eagerness to reduce trade barriers and to draw FDI into the country. On the other hand, India's growth has been capitalized by the quick extension of service-creating industries. Qureshi and Wan (2008) showed that China is the competitor of India in the third markets exclusively in clothing, textile and leather products. China is a challenge for the US, the European countries, and the East Asian region especially in medium-technology industries; India is the competitor mainly for South Asian countries. The researchers Singh et al. (2009) found that China and India have implemented numerous promotional schemes for SMEs. Bansal (2011) compared the growth of e-commerce and internet development in China and India. They reveal that despite China joined to the Internet later, it is now more advanced of India implementing special "Golden Projects" and the speedy development in the Internet infrastructure.

The study conducted by Marelli and Signorelli (2011) revealed that openness, FDI, and integration in the world economy have an important positive impact on economic growth of these two countries. Agrawal and Khan (2011) documented that 1% increase in FDI would produce 0.07% increase in GDP of China and 0.02% addition in GDP of India. Lema and Lema (2012) illustrated that traditional technology transfer process like FDI and licensing was vital for industry build up and leap forward initially for China and India. But, since these sectors are catching up, new non-traditional technology transfer techniques like R & D joint ventures and foreign firm's acquisition have become essential. Incorporating the comparative advantage theory with Dunning's OLI paradigm on China and India's MNEs, Sun et al. (2012) showed that MNEs from developing economies have gone for aggressive overseas mergers and acquisitions (M and As).

Jayanthakumaran et al. (2012) illustrated that CO_2 emissions in China had been persuaded by energy consumption, per capita income, and structural changes. On the contrary, the same relationship cannot be established for India. The reason is the informal economy of India is larger than that of China. India has a good number of micro-enterprises which consumes low energy. In an empirical study to compare growth and productivity between China and India Wu et al. (2017) revealed that the growth of China in value added was over 50% faster but in TFP 25% slower than that of India after the reform started. In a review article by Adhikari and Ganguly (2017) explained the comparative green industrial policies of China and India.

Pradhan et al. (2017) revealed that carbon prices are higher in China than India because of the differences in emission intensity and in the rate of deployment of new technologies. The study by Yao and Whalley (2017) documented that China was adversely affected by the crisis than India and India is recovering more rapidly in economic performance. India has diversified its exports and China's share has dropped. India has a more competitive advantage in the service sector. Wolde-Rufael and Idowu (2017) showed that there had been no considerable relationship between income inequality and CO_2 emissions both in the short-run and in the long-run in India and China.

Applying the ARDL model Pal and Mitra (2017) revealed that there is a short-run effect of energy use on CO_2 emissions and a long-run impact of economic growth and trade openness. Their study also documented the N-shaped relationship between CO_2 emissions and economic growth between India and China. Nguyen et al. (2017) demonstrated that investment plays a crucial role in the relationship between energy consumption, carbon emissions and income in China but not in India. They also showed that trade openness plays a major role in the short-term in China but it has no effect on the energy-emissions-growth situation in India. Solarin et al. (2017) proved the existence of the EKC hypothesis in both the countries. The study documented that real GDP and urbanization have a long-run positive effect on emission but hydroelectricity consumption has a negative impact on it in the long-run in both countries. The Granger causality test revealed that there had been a long-run bidirectional relationship between the variables.

In a study, Sun et al. (2018) documented that the use of total energy in bilateral trade and net embodied energy imports in India's manufacturing increased by 11 times and 40 times respectively. The manufacturing sector of India lost its benefit of energy preservation slowly followed by the trade deficit. India's light industries had reduced trade profits and increased energy demands but it had been the heavy industries in the case of China. The study conducted by Shahbaz et al. (2018) revealed that industrialization, urbanization, and service sector growth facilitated in the financial development of China and India. The study added that trade openness increases Indian financial development which is not documented for China and the institutions and governments might play a major role for both countries in enlarging finance and growth. Nazir and Tan (2018) confirmed that financial innovation has a positive and significant effect on economic growth in the short-run and long-run. It was also revealed in the study that trade openness and gross capital formation plays important role in the economic growth.

The role of technology in economic growth has been explained in the neoclassical growth theory introduced by Solow (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 (Oulton, 2012; Romer, 1990). A large and growing body of literature has examined the technology - economic growth relationships and most of the researchers found the positive impact of technology on economic growth which has been mentioned in the introduction section. In the previous study, Hardy (1980) revealed that telephones contribute to the economic development. Madden and Savage (1998) found a positive relationship between investment in telecommunication infrastructure and economic growth. Brynjolfsson and Hitt (2003) confirmed that firms that have invested in computer technology had been able to realize higher productivity.

The study by 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 productivity growth and surplus gains to the non-ICT wealth. Similarly, (Atzeni and Carboni, 2006; Fabiani et al., 2005) investigated the data of Italian manufacturing firms and demonstrated that ICT investments have a significant effect on output. The similar results were documented in the study of (Chavula and Chekol, 2013; Sassi and Goaied, 2013; Seo et al., 2009; Stiroh, 2002; Vu, 2011; 2013).

The researcher Koutroumpis (2009) revealed that broadband penetration has a positive effect on the economic growth in 22 OECD countries. Gruber and Koutroumpis (2010) illustrated the significant effect of mobile telecommunications on output and GDP. Ahmed and Ridzuan (2013) investigated the impact of ICT on economic growth for ASEAN5+3 countries, revealed that capital, labor, 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 growing GDP per capita and trade openness create a rebound effect of technological innovation on energy use. Shahbaz et al. (2016) revealed that ICT increases electricity demand and there is a feedback or bi-directional effect exists between economic growth and electricity consumption in UAE. Kumar et al. (2017) demonstrated that mobile technology has a significant positive long-run and short-run effect on the productivity and a bi-directional causality exists between mobile technology and GDP per capita in Zimbabwe.

Some of the scholars discovered the mixed or negative impact of technology on economic growth. Lee et al. (2005) demonstrated that ICT has a positive effect on the economic growth in many developed countries and newly industrialized countries but not in developing economies. Ishida (2015) revealed that ICT investment contributes to a modest decline in energy but does not boost GDP in Japan.

There are a good number of studies which found the positive relationship between economic growth and CO_2 emission. Grossman and Krueger (1991) and Selden and Song (1994) developed the EKC hypothesis which illustrates that economic growth and environmental degradation is inverted-U shaped and non-linear. It refers that economic growth leads to a steady deterioration of the environment but after a definite stage of economic growth, it starts to improve again. The same results were found in many studies which have been mentioned in the introduction section.

Poumanyvong and Kaneko (2010) and Poumanyvong et al. (2012) revealed that the impact of urbanization on energy consumption and CO_2 emissions fluctuate with the stage of development. Hossain (2011) revealed that there is no long-run relationship running, but unidirectional short-run relationship prevails from economic growth to energy consumption, from economic growth and trade openness to CO_2 emissions, from trade openness to economic growth. Zhang and Lin (2012) documented that urbanization augmented energy use and CO_2 emissions at the national stage but it fluctuates at the regional level.

In a study, Sadorsky (2014) documented that raise in income stimulates energy consumption for both short-run and long-run. Al-Mulali and Ozturk (2016) revealed that financial development, economic growth, and urbanization intensify CO_2 emission in the long-run, whereas trade openness reduces it. Renewable electricity has the long run negative effect on CO_2 emission. The VECM Granger causality reported that only economic growth caused CO_2 emission in the long-run. Al-Mulali et al. (2015) documented that trade openness, energy consumption, industrial development, and urbanization is the reason of environmental degradation but political stability lessens it. Magazzino (2016) documented that energy use drives the real GDP for three GCC countries - Kuwait, Oman, and Qatar.

Dogan and Turkekul (2016) showed the non-existence of the EKC hypothesis in the USA. They documented that energy consumption and urbanization enlarge environmental degradation but there is no effect of financial development on it in the long run. Their study added that trade has a negative effect on environmental degradation as well as energy policies reduce CO_2 emissions without damaging sustainable growth. The partial similar result was found in the study of (Javid and Sharif, 2016; Kang et al., 2016) for Pakistan and China. Ali et al. (2016) expressed that energy consumption and economic growth has a positive effect on CO_2 emissions in

Nigeria but it is not documented for urbanization. On the other hand, Trade openness has a significant and negative impact on CO_2 emissions. Kahia et al. (2017) documented the bidirectional causality among renewable and non-renewable energy use and economic growth. The study conducted by Jamel and Maktouf (2017) on 40 European countries revealed the validity of the environmental Kuznets curve hypothesis. They also demonstrated the bidirectional causality running between financial development, economic growth, trade openness, and environmental degradation.

Some of the researchers documented the mixed or negative effect of economic growth on CO_2 emissions. Liu et al. (2007) revealed the presence the EKC for Shenzhen. They documented that production-induced pollutants supported EKC but consumption-induced pollutants did not maintain it. Hossain (2012) demonstrated that more consumption of energy increase environmental pollution, on the contrary, trade openness, economic growth, and urbanization does not affect environmental standard in the long-run in Japan. Chandran and Tang (2013) illustrated that economic growth plays a crucial role in increasing CO_2 emission in ASEAN-5 countries. They documented that the inverted U-shape EKC hypothesis is not appropriate for these economies, especially in Malaysia, Indonesia, and Thailand. The bi-directional causality is running between economic growth and CO_2 emissions in Indonesia and Thailand in the long run, while unidirectional causality running from GDP to CO_2 emissions in Malaysia.

Farhani and Ozturk (2015) showed that financial development has a positive impact on CO_2 emissions, as well as a positive monotonic relation sustain between CO_2 emissions and GDP which deviated from the EKC hypothesis in Tunisia. The study conducted by Jebli and Youssef (2015) on Tunisia documented short-run unidirectional causality running from the GDP, trade, CO_2 emission, and non-renewable energy to renewable energy. In addition, non-renewable energy and trade have a positive impact on CO_2 emissions, while renewable energy has a negative and negligible effect on CO_2 emissions.

A large number of studies revealed the positive impact of trade openness on economic growth which has been mentioned in the introduction section. In the study, Yanikkaya (2003) documented the positive relationship between trade and growth through comparative advantage, scale economies, and technology transfers. Applying ARDL and Toda and Yamamoto Granger causality approach to revisiting the crucial role of trade openness, energy and financial development of South Africa Kumar et al. (2015) revealed a unidirectional causality between trade openness and output. Were (2015) illustrated that trade has a positive impact on economic growth in developed and developing countries but no effect for least developed countries like African countries.

Rafindadi and Ozturk (2016) revealed exports, imports, and trade openness positively increase electricity consumption as well as economic growth in Japan. Ertugrul et al. (2016) revealed that the EKC hypothesis exists in China, Turkey, Korea and India. The research work also showed that energy consumption, trade openness, and real income are the principal determinants of carbon emissions in the long run. Pradhan et al. (2017) demonstrated that there is a general long-run as well as the short-run positive relationship among banking sector depth, trade openness, and economic growth.

Didier and Pinat (2017) demonstrated that increases in the level of intra-industry trade, participation in global value chains, and increases in the shares of different goods increases income. They also showed that technological diffusion and learning spillovers play a crucial role in the growth of trade. In a study by (Nursini, 2017) revealed that trade openness has a strong and positive impact on economic growth in Indonesia.

Some study found the mixed or negative effect of trade openness on economic growth. (Kim, 2011) illustrated that there is a significant positive effect of trade openness on growth and real income for the developed countries; on the contrary, it has negative effects for the developing countries. Menyah et al. (2014) revealed that there is an inadequate support for trade-driven growth proposition for the 21 SSA (Sub-Sahara Africa) countries. Trejos and Barboza (2015) showed that trade openness is not the major component in illustrating the Asian economic growth miracle. They revealed that trade openness has a strong positive effect on output growth at the regional level only. Busse and Groizard (2008) revealed that overall trade is negatively associated with per-capita income. (Jawaid et al., 2011) showed trade policy has a trivial effect on economic growth in the case of Pakistan. Musila and Yiheyis (2015) documented that the role of trade openness on economic growth is insignificant and trade-policy has a negative effect on economic growth on Kenya.

Reviewing the existing literature, we find that numerous researcher conducted lots of study on different variables and applying different methods to compare China and India. But few types of research have been conducted about the impact of Technological innovation, Trade openness and CO_2 emission on Economic growth. So far as our findings, we have studied the relationships of these four variables for these two countries for the 1st time. For this reason, this study holds a great importance in the literature arena and it will fill up the gap in the existing economic literature.

3. DATA AND ECONOMETRIC MODEL

With a view to examine and compare the long and short run relationships between Technological innovation, Trade openness, CO_2 emission and Economic growth of China and India, data have been taken from the world highly reliable data source - WDI of the World Bank - published in 2017. It has covered the period from 1974 to 2016 which is the longest time series data been used so far. For Economic growth, we would use GDP per capita (constant 2010 US$); for CO_2 emissions, we will take CO_2 emissions (kg per 2010 US$ of GDP); for trade openness, we will utilize the total of export and import as per cent of GDP. We have taken the number of patents applied by residents and non-residents (sum) as a proxy for technological innovation (TI). It can be mentioned that Technological innovation refers the concern of industrial and private organizations of a country in searching a new technology and could be expressed by a quantitative indicator, such as the number of patents. In this situation, following the empirical studies of (Ang, 2009), (Schmoch, 2007), (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. We have converted all time series data to their natural logarithm form except Trade openness because it is in percentage (ratio) form.

In order to realize and understand the important findings into the short-run and long-run relations and the causality between Technological innovation, Trade openness, CO_2 emission and Economic growth of China and India, three variables have been used in the growth form and only Trade Openness has been used in the ratio form. But the data of trade openness also has been derived from the growth form of export, import, and GDP. By utilizing a variable in growth form indicates the information about the course of movements of the variable in the current period with the previous period. It illustrates the vibrant relations among the related variables and can be utilized to acquire valuable insight in respect of the future movement of the variables (Rahman and Kashem, 2017).

In our study, we are going to use GDP per capita (GDP) as the dependent variable and technological innovation (TI), Trade openness (TO) and CO_2 emission (CO_2) as the explanatory variables. In order to document the principal objective of our research, the functional form of the model has been designed as follows:

$$GDP = f\,(TI,\ TO,\ CO_2) \tag{1}$$

Reviewing the past literature and following the study of (Rahman and Kashem, 2017; Shahbaz et al., 2018) the linear econometric form of the above model is as follows:

$$GDP_t = \propto_0 + \propto_1 TI_t + \propto_2 TO_t + \propto_3 CO_{2t} + \varepsilon_t \tag{2}$$

In the above equation, $\propto_0$ is the intercept and $\propto_1$, $\propto_2$, and $\propto_3$ are coefficients of the explanatory variables. ε refers to the error term and the subscript *t* explained the time period. By taking the natural logarithm of the variables in both sides except, "trade openness" (because it is in the ratio form), the equation stands as follows:

$$lnGDP_t = \propto_0 + \propto_1 lnTI_t + \propto_2 TO_t + \propto_3 lnCO_{2t} + \varepsilon_t \tag{3}$$

3.1. Unit Root Testing

It is known that unit root test is not essential in ARDL method, because of this approach 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 this two. But the study of Pesaran and Shin (1998) and Pesaran et al. (2001) illustrated that in ARDL Bounds test none of the variables should be integrated into the order *I(2)*. If the variables are integrated into the order *I(2)*, it would quash the methodology of the test. For this reason, it is necessary to justify the stationarity of time series variables before going to the next level of investigation. In addition, according to the conventional unit root testing approach, it is presumed that random shocks would have temporary effects and would not affect in the long-run on the economy. The study by Nelson and Plosser (1982) revealed that economic rise and falls 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, energy consumption; trade etc. faces structural changes mainly in the developing countries. Besides, according to Perron (1989) conventional unit root tests like ADF presents biased results towards the non-rejection of the null hypothesis of a unit root in the presence of structural break. Considering all these things, we will utilize structural breakpoints using Bai and Perron (2003) multiple breakpoint tests and we would again perform structural break unit root tests in the modified ADF and PP test.

3.2. Test of Cointegration in ARDL Bounds

There have been various approaches to test the presence of the cointegration and the short-run and long-run relationships among or between the variables. We would apply the ARDL Bounds Testing approach in this study. It is well known that the ARDL bound testing method has a number of smart features over traditional cointegration testing approach. The features are: (a) This method has the supremacy on other methods and allows to analyze the data in the presence of cointegration of I(0) or I(1); (b) it has the elasticity and for single equation set up it could be easily utilized and illustrated; (c) it could be applied for small observations; (d) in this procedure different lag-lengths for different variables could be used; (e) unbiased result of short-run relationships and long-run dynamics of the variables are presented in this method and (f) it eliminates the auto-correlation and endogeneity problems so far as possible.

The results of the error correction model in the ARDL approach indicate the velocity of adjustment reverse to the long run stability after a short run shock. The ECM incorporates the short-run coefficient with the long-run without dropping long-run information. In this process, the long run causality is illustrated by the negative and significant value of the error correction term (ECT) coefficient and the short run causality is indicated by the important value of coefficients of additional explanatory variables (Rahman, 2017; Rahman and Kashem, 2017; Shahbaz et al., 2013). Following the above-mentioned researchers for bounds testing of cointegration, the ARDL model used in this study is:

$$\Delta lnGDP_t = \begin{array}{l} \propto_0 + \sum_{i=1}^{\rho} \propto_1 \Delta lnGDP_{t-i} + \sum_{i=1}^{\rho 1} \propto_2 \Delta lnTI_{t-i} + \\ \sum_{i=1}^{\rho 2} \propto_3 \Delta TO_{t-i} + \sum_{i=1}^{\rho 3} \propto_4 \Delta lnCO_{2t-i} + \\ \beta_1 \Delta lnGDP_{t-1} + \beta_2 \Delta lnTI_{t-1} + \beta_3 \Delta TO_{t-1} + \\ \beta_4 \Delta lnCO2_{t-i} + \varepsilon_t \end{array} \tag{4}$$

The model produced above is a unique category of Error Correction Model (ECM) and the coefficients of the model are not controled. In the model, ε_t is well-behaved random disturbance terms which are serially independent, homoskedastic and normally distributed. Pesaran et al. (2001) mentioned this special type of ECM as the conditional ECM. The terms with summation signs express the error correction dynamics for the short run and the terms with β depicted to the long-run relationships among the variables

(Rahman, 2017; Rahman and Kashem, 2017). The maximum lag lengths ρ, ρ1, ρ2 and ρ3 would be realized by applying one or more of the 'information criteria' such as AIC, SC, HQ, etc. The null and alternative hypotheses of the above-mentioned equation would be as follows:

H_0: No cointegration exists.

H_1: Cointegration exists.

The null hypothesis of the model would be tested by applying 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:

$H_0 : \beta_1=\beta_2=\beta_3=0$

$H_1 : \beta_1\neq0,\ \beta_2\neq0,\ \beta_3\neq0$

The researcher Pesaran et al. (2001) introduced the critical values of the F-statistic for the asymptotic distribution about the bounds testing method. In this procedure, they developed upper and lower bounds on the critical values for various situations. In accordance with 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 investigation short-run parameters will be calculated by applying the regular error correction mechanism (ECM) expressed in the Model produced above (equations 1-4):

$$\Delta lnGDP_t = \begin{array}{l} \propto_0 + \sum_{i=1}^{\rho} \propto_1 \Delta lnGDP_{t-i} + \sum_{i=1}^{\rho1} \propto_2 \Delta lnTI_{t-i} + \\ \sum_{i=1}^{\rho2} \propto_3 \Delta TO_{t-i} + \sum_{i=1}^{\rho3} \propto_4 \Delta lnCO_{2t-i} + \\ \gamma ECT_{t-1} + \varepsilon_t \end{array} \quad (5)$$

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

3.3. Diagnosis Test of the Model

In our study, we would apply the traditional methods to diagnosis the model. In accordance with the ARDL Bounds testing approach, it is necessary and essential assumptions that the errors of Equations 4 and 5 must be identically and independently distributed. In order to recognize 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. At last, "Breusch-Pagan-Godfrey" test will be applied to specify the heteroscedasticity of the model.

3.4. Stability Test of the Model

To ensure the stability of the model that has the autoregressive features in nature is essential. According to the suggestion of (Pesaran and Pesaran, 1997) and following (Brown et al., 1975) recursive CUSUM and CUSUM of squares tests would be utilized to confirm the stability of the model.

3.5. Toda-Yamamoto Granger Non-Causality Test

In our study, we are going to apply the ARDL approach to analyze the cointegration, short-run relationships, and long-run dynamics. But Granger (1969) commented 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 validate causation between or among variables. So on the basis of the above discussion; we should go for a cross-check of our findings. In this study, we would use the Toda-Yamamoto Granger non-causality test to establish the relationships and the directions of our variables again.

Toda and Yamamoto (1995) introduced a technique to examine the existence of non-causality whether the variables are *I(0), I(1) or I(2)*, cointegrated or not cointegrated of an arbitrary order. It can be applied by a traditional lag selection system of VAR since the order of integration of the process does not surpass the actual lag length of the model (the standard asymptotic theory). In this procedure, after determining a lag length k, (k + dmax)th order of VAR is calculated. Here, dmax is the highest order of integration which might occur in the process. They stated in the study that the coefficient matrices of the previous dmax lagged vectors in the model are overlooked because of these are considered as zero and it can be checked linear or nonlinear limitations on the first k coefficient matrices utilizing the standard asymptotic theory. According to the Toda and Yamamoto procedure, the causality model is built in the following VAR system:

$$\Delta lnGDP_t = \begin{array}{l} \propto_0 + \sum_{i=1}^{\rho} \propto_{1i} \Delta lnGDP_{t-i} + \sum_{j=\rho+1}^{d\,max} \propto_{2j} \Delta lnGDP_{t-j} + \\ \sum_{i=1}^{\rho1} \propto_{3i} \Delta lnTI_{t-i} + \sum_{j=\rho1+1}^{d\,max} \propto_{4j} \Delta lnTI_{t-j} + \\ \sum_{i=1}^{\rho2} \propto_{5i} \Delta TO_{t-i} + \sum_{j=\rho2+1}^{d\,max} \propto_{6j} \Delta TO_{t-j} + \\ \sum_{i=1}^{\rho3} \propto_{7i} \Delta lnCO_{2t-i} + \sum_{j=\rho3+1}^{d\,max} \propto_{8j} \Delta lnCO_{2t-j} + \varepsilon_{1t} \end{array} \quad (6)$$

$$\Delta lnTI_t = \begin{aligned} &\beta_0 + \sum_{i=1}^{\rho}\beta_{1i}\Delta lnTI_{t-i} + \sum_{j=\rho+1}^{d\,max}\beta_{2j}\Delta lnTI_{t-j} + \\ &\sum_{i=1}^{\rho 1}\beta_{3i}\Delta lnGDP_{t-i} + \sum_{j=\rho 1+1}^{d\,max}\beta_{4j}\Delta lnGDP_{t-j} + \\ &\sum_{i=1}^{\rho 2}\beta_{5i}\Delta TO_{t-i} + \sum_{j=\rho 2+1}^{d\,max}\beta_{6j}\Delta TO_{t-j} + \\ &\sum_{i=1}^{\rho 3}\beta_{7i}\Delta lnCO_{2t-i} + \sum_{j=\rho 3+1}^{d\,max}\beta_{8j}\Delta lnCO_{2t-j} + \varepsilon_{2t} \end{aligned} \quad (7)$$

$$\Delta TO_t = \begin{aligned} &\gamma_0 + \sum_{i=1}^{\rho}\gamma_{1i}\Delta TO_{t-i} + \sum_{j=\rho+1}^{d\,max}\gamma_{2j}\Delta TO_{t-j} + \\ &\sum_{i=1}^{\rho 1}\gamma \propto_{3i} \Delta lnTI_{t-i} + \sum_{j=\rho 1+1}^{d\,max}\gamma_{4j}\Delta lnTI_{t-j} + \\ &\sum_{i=1}^{\rho 2}\gamma_{5i}\Delta lnGDP_{t-i} + \sum_{j=\rho 2+1}^{d\,max}\gamma_{6j}\Delta lnGDP_{t-j} + \\ &\sum_{i=1}^{\rho 3}\gamma_{7i}\Delta lnCO_{2t-i} + \sum_{j=\rho 3+1}^{d\,max}\gamma_{8j}\Delta lnCO_{2t-j} + \varepsilon_{3t} \end{aligned} \quad (8)$$

$$\Delta lnCO_{2t} = \begin{aligned} &\delta_0 + \sum_{i=1}^{\rho}\delta_{1i}\Delta lnCO_{2t-i} + \sum_{j=\rho+1}^{d\,max}\delta_{2j}\Delta lnCO_{2t-j} + \\ &\sum_{i=1}^{\rho 1}\delta_{3i}\Delta lnTI_{t-i} + \sum_{j=\rho 1+1}^{d\,max}\delta_{4j}\Delta lnTI_{t-j} + \\ &\sum_{i=1}^{\rho 2}\delta_{5i}\Delta TO_{t-i} + \sum_{j=\rho 2+1}^{d\,max}\delta_{6j}\Delta TO_{t-j} + \\ &\sum_{i=1}^{\rho 3}\delta_{7i}\Delta lnGDP_{t-i} + \sum_{j=\rho 3+1}^{d\,max}\delta_{8j}\Delta lnGDP_{t-j} + \varepsilon_{4t} \end{aligned} \quad (9)$$

The four equations mentioned above have been designed to conduct Toda-Yamamoto Granger non-causality test to establish the relationships and the directions of our variables. The null hypothesis of no-causality is refused when the p-values remain within the desired 1% to 10% level of significance. In equation 6, Granger causality is running from TI, TO and CO_2 to GDP implies that $\propto_{3i}\neq 0$, $\propto_{5i}\neq 0$, and $\propto_{7i}\neq 0$ respectively. The same test will be conducted for the equation 7-9. We would fix the proper highest lag length for the variables in the VAR by applying the regular process such as AIC. We would also confirm that VAR is well specified.

4. 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.

The Table 1 indicates the mean, median and standard deviation of the series. The results of the Jarque-Bera test showed that GDP and Technological innovation data of China and India are significant, means they are not normally distributed. Since we will convert these data into their natural logarithm form and also we will cross-check it after running the model, it is not a problem. The correlation matrix illustrates a positive correlation of Technological innovation and Trade openness of both the countries on Economic growth; on the other hand, CO_2 has a negative correlation with Economic growth as well as other variables.

4.1. 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. In line with the discussion of our unit root methodology section, we checked structural breakpoints using Bai and Perron (2003) multiple breakpoint tests and the results displayed in Appendix 1. The results indicated that there are several structural breaks of the variables Technological innovation, Trade openness, CO_2 emission and Economic growth in different years. Then we conducted structural break unit root tests in the modified ADF test and the results are as follows (Table 2):

The results obtained from the structural break unit root tests in the modified ADF 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 the results of the structural break unit root tests fulfill the conditions to apply the ARDL approach in this study.

4.2. Estimation of ARDL Model

Lag selection order of the variables is very important for the specification of the model in accordance with the ARDL method.

Table 1: Descriptive statistics and correlation of variables

Variables	China				India			
	GDP	TI	TO	CO_2	GDP	TI	TO	CO_2
Mean	1902.30	205564.8	33.2733	2.6697	781.01	14260.20	26.2299	1.1996
Median	1173.02	51906.00	33.8098	2.2941	622.30	4826.00	21.6941	1.1731
SD	1851.34	298286.6	16.5662	1.2375	428.28	15228.48	15.2026	0.1174
Jarque-Bera	10.2537	20.41586	1.74500	4.1575	7.9360	8.2429	5.3714	2.9410
Probability	0.0059	0.0000	0.41790	0.1250	0.0189	0.0162	0.0681	0.2298
Correlation								
GDP	1.0000				1.0000			
TI	0.9486	1.0000			0.9685	1.0000		
TO	0.6749	0.4799	1.0000		0.9694	0.9703	1.0000	
CO_2	−0.7701	−0.5972	−0.7808	1.0000	−0.4551	−0.5839	−0.4888	1.0000

Source: Author's own calculation in Eviews

Table 2: Unit root tests with structural break

Variable	India							
	SC (Level)		SC (first difference)		AC (level)		AC (first difference)	
	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend	Intercept	Intercept and trend
lnGDP	−0.5287 (0.99)	−5.6461*** (0.01)	−6.0542*** (0.01)	−5.7205*** (0.01)	0.2971 (0.99)	−5.5504*** (0.01)	−5.7463*** (0.01)	−4.8624** (0.04)
lnTI	−0.5503 (0.99)	−3.5825 (0.64)	−6.9039 (0.01)	−6.7782*** (0.01)	−0.5503 (0.99)	−3.5771 (0.64)	−6.3803*** (0.01)	−6.7782*** (0.01)
lnTO	−1.8536 (0.98)	−2.3306 (0.99)	−5.4260 (0.01)	−5.3786*** (0.01)	−2.2073 (0.96)	−2.4815 (0.98)	−5.2424*** (0.01)	−5.0597** (0.02)
lnCO2	−2.0088 (0.98)	−3.8848 (0.44)	−4.3579* (0.06)	−5.9554*** (0.01)	−1.9250 (0.98)	−3.8848 (0.44)	−4.5421** (0.03)	−5.9554*** (0.01)
India								
lnGDP	0.3490 (0.99)	−2.1379 (0.99)	−7.2807*** (0.01)	−7.8010*** (0.01)	0.3490 (0.99)	−3.1503 (0.86)	−7.2807*** (0.01)	−7.7697*** (0.01)
lnTI	−2.7224 (0.82)	−4.8652** (0.04)	−5.5067*** (0.01)	−7.6513*** (0.01)	−2.7224 (0.82)	−4.8652** (0.04)	−5.5067*** (0.01)	−5.8875*** 0.01
lnTO	−2.2044 (0.96)	−6.6102*** (0.01)	−6.8767*** (0.01)	−7.9851*** (0.01)	−2.4263 (0.92)	−6.6102*** (0.01)	−6.8767*** (0.01)	−5.8077*** (0.01)
$lnCO_2$	−3.4432 (0.41)	−4.6724* (0.08)	−7.0715*** (0.01)	−7.4085*** (0.01)	−3.4432 (0.41)	−4.6724* (0.08)	−6.7626*** (0.01)	−7.4085*** (0.01)

Source: Author's own calculation in Eviews

Akaike information criterion (AIC) has been applied to select the proper lag length for the model in our study. In the study of Lütkepohl (2006) documented that AIC has superiority for small sample data in comparison to any lag length criterion such as Schwarz information criterion (SC) and Hannan–Quinn information criterion (HQ). AIC presents efficient and reliable results as compared to ultimate forecast error. The selected model for China is ARDL (1, 5, 6, 6) and for India is ARDL (1, 0, 1, 1). According to the result of AIC, the optimum lag lengths of the variables lnGDP, lnTI, TO and $lnCO_2$ are: ρ = 1, ρ1 = 5, ρ2 = 6, ρ3 = 6 respectively for China and ρ = 1, ρ1 = 0, ρ2 = 1, ρ3 = 1 respectively for India.

4.3. Diagnostic Test of the Model

With a view to confirming the stability and fitness of our model, we operated Normality test (Jarque-Bera,) serial correlation test (Q-Statistics and Breusch-Godfrey Serial Correlation LM tests), and Heteroscedasticity test ("Breusch-Pagan-Godfrey").

The results obtained from the different diagnostic tests are provided in Table 3. According to the Table 4, the R^2 is 0.9792 and adjusted R^2 is 0.5951 of the model for China and the R^2 is 0.8336 and adjusted R^2 is 0.5192 of the model used for India. The results of the analysis illustrate that >97% and 83% dissimilarity in the dependent variables are elaborated by the model designed for China and India respectively and the rest by the error terms. The probability of F-statistics and observed R^2 test documented that our model passed almost all the tests regarding serial correlation, Normality and Heteroscedasticity tests. Only observed R^2 is significant of the model used for China whereas, F- statistics of this model is not significant. So we can ignore it and run our model. In this situation, we can conclude that this model is well designed and passes almost all the diagnostic tests.

4.4. Bound Test

Since the basic tests of the model passed almost all the necessitated diagnostics tests, we are going to turn to the next stage of investigation which is called the bounds test for cointegration.

The result of ARDL bounds test revealed that F-test is 16.8961 of the model used for China and F-test is 28.5632 of the model used for India. The value of the estimated F-statistic of our models has exceeded the upper bound at the 1% level of significance. It is apparent from the result that there is a long-run relationship exists among Technological innovation, Trade openness, CO_2 emission and Economic growth.

4.5. Long Run Dynamics

We have calculated the long-run equilibrium relationship between the variables applying the ARDL (1, 5, 6, 6) for China and ARDL (1, 0, 1, 1) for India. The result of the long-run estimation is summarized in the Table 5 below:

The results of the above Table 5 illustrate that Technological innovation, Trade openness and CO_2 emission has a significant and positive effect on the Economic growth of China at 1% level in the long run; whereas, Technological innovation is not significant for India in the long run which has an important policy implication for India. Only Trade openness and CO_2 emission have a positive impact on the Economic growth of India at 5% level of significance. By analyzing the coefficients of the variables, we observed that 1 unit increase of Technological innovation in China would intensify 0.55 unit Economic growth. On the other hand, Technological innovation is not significant for Economic growth in India. These findings refer that Technological innovation is playing a stronger and significant role in the Economic growth of China but this is not established for India. The ranking of Technological readiness of India (107) is far behind not only of China (73) but also from the other countries of the world. So India has enormous space to improve its technological sector.

In line with Technological innovation, Trade openness is also keeping a crucial role in the Economic development of China. Our empirical result indicates that 1 unit increase of Trade openness in China would increase 0.95 unit Economic growth. On the other hand, 1 unit increase of Trade openness would increase by only 0.01 unit Economic growth in India. It is referred by this finding that China has a more open economy than India and it is enjoying the benefits of it.

The result of our study clearly documented that the use of energy is still playing a significant and crucial function in the economic development of both the countries. It is revealed that 1(one) unit increase of CO_2 emissions means in energy use would increase 1.03 unit Economic growths in China. On the other hand, 1 unit increase of CO_2 emissions would increase 1.13 unit Economic growths in India. So the use of energy is very much important for China and India to keep up the present economic development.

For China, in the long run, our findings are consistent with the result of (Ahmed and Ridzuan, 2013; Nazir and Tan, 2018; Pal and Mitra, 2017; Sohag et al., 2015; Solarin et al., 2017) and it is against the findings of (Busse and Groizard, 2008; Ishida, 2015). In the case of India, our findings are similar to the result of (Ishida, 2015; Nazir and Tan, 2018; Pal and Mitra, 2017) and it is against the findings of (Ahmed and Ridzuan, 2013; Sohag et al., 2015) in the long run.

4.6. Short Run Analysis

After explaining the long run relationship of the variables, now we move to elaborate the short-run causality in ARDL (1, 5, 6, 6) for China and ARDL (1, 0, 1, 1) for India. The result is shown in the Table 6 below:

The results of the short run analysis reveal that short-run dynamics are also running so as the long-run relationships among the investigated variables in China and India. For China, the sign of lagged error correction term (ECT) - Coint Eq (-1) is negative and significant at 5% level and for India, it is 10% level of significance. This figure and sign represent that there is the presence of a long-term association between the dependent variables and the regressors for both the countries.

In the case of China, the value of ECT coefficient is −0.8805 which indicates significant and a faster velocity of modification

Table 3: Diagnostic test

Test	China		India	
	F test (Probability)	Observed R^2	F test (Probability)	Observed R^2
Breusch-Godfrey Serial Correlation LM test	0.1929	0.0001	0.8023	0.7772
Breusch-Pagan-Godfrey heteroskedasticity test	0.4285	0.3562	0.0637	0.0725
Jarque-Bera test	0.6905	0.7080	0.6817	0.7111
	China		India	
R^2	0.9792		0.8336	
Adjusted R^2	0.5951		0.5192	

Source: Author's own calculation in Eviews

Table 4: Bound test for cointegration

Test statistics	China		India	
F Statistic	16.8961		28.5632	
Number of independent variables-k	3		3	
Critical values (%)	**Lower bound**	**Upper bound**	**Lower bound**	**Upper bound**
1	3.65	4.66	3.65	4.66
5	2.79	3.67	2.79	3.67
10	2.37	3.2	2.37	3.2

Source: Author's own calculation in Eviews

Table 5: Estimated long-run coefficients in ARDL

Dependent variable: GDP					
China			India		
Variable	Coefficient	t-Statistic	Variable	Coefficient	t-Statistic
LNTI	0.5554***	25.9928	LNTI	0.0414	0.4269
TO	0.9565***	14.2633	TO	0.0147**	2.1012
$LNCO_2$	1.0331***	7.2510	$LNCO_2$	1.1371**	2.3877
C	−1.3489***	−6.3932	C	2.1561***	3.0725

Source: Author's own calculation in Eviews

to equilibrium. Thus nearly 88% of the disequilibrium returns to the long-term stability within 1 year in China. The impact of the current period, as well as different lag periods of Technological innovation, Trade openness and CO_2 emissions on Economic growth, are mixed. These three variables have both positive and negative significant impact on Economic growth in the short-run which is determined by the sign and significance of the coefficients. For China, both the results obtained from the long-run and short-run analysis reveals that Technological innovation, Trade openness and CO_2 emissions have the positive and strong effect on Economic growth in the long-run.

For India, the value of ECT coefficient is −0.0914 which signifies the momentum of adjustment to stability but it is weaker than China. Thus nearly 9% of the disequilibrium converges back to the long-term equilibrium within 1 year in India. Technological innovation and Trade openness is not significant on Economic growth in the short-run. Only CO_2 emissions have a significant and negative impact on Economic growth in the short-run.

In the case of China, our findings are similar to the result of Nguyen et al. (2017) in the short-run. For India, in the short-run, our findings is similar to the result of Sikdar and Mukhopadhyay (2018) and it is against the findings of Nguyen et al. (2017).

4.7. Stability of the Model

In order to confirm the robustness of the long-run dynamics and short-run results of our analysis for China and India, we have applied the structural stability tests on the parameters based on the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests suggested by (Pesaran and Pesaran, 1997). Graphs 1-4 are presented below:

The graphical representation of CUSUM and CUSUMSQ statistics has been provided in Graphs 1 and 2 for China and Graphs 3 and 4 for India. It is established in research that if the plots of the CUSUM and CUSUMSQ stay within the 5% critical bound, it would confirm the reliability of the parameter and stability of the model. The graphical representation of both the models reveals that none of the straight lines (drawn at the 5% level) are exceeded by CUSUM and CUSUMSQ. It refers that the plots of both the CUSUM and CUSUMSQ methods remain within the boundaries.

4.8. Toda-Yamamoto Granger Non-causality Test

The bound tests in the ARDL approach have illustrated the long-run causality and short-run relationships among our respective variables. We want to utilize the Toda-Yamamoto Granger non-causality test to confirm the directions and causality between the variables for the cross-check of our findings. In this test, we want to determine unilateral, bidirectional or no directional causality running among Technological innovation, Trade openness, CO_2 emission and Economic growth for China and India. The result obtained from the mentioned test has been presented in Table 7.

The results obtained from the Toda-Yamamoto Granger causality test reveals that bi-directional causality is running between Economic growth and Trade openness, between Technological innovation and CO_2 emissions as well as a unidirectional causality is running from Technological innovation and CO_2 emissions to Trade openness for China. On the other hand, our obtained results express that there is a unidirectional causality running from Economic growth, Technological innovation, and Trade openness to CO_2 emissions as well as from Technological innovation to Trade openness for India. The findings of this test support the results obtained in the ARDL approach in our study.

For China, in accordance with the result of Granger Causality Test, our findings are similar to the result of (Kumar et al., 2015; Nazir and Tan, 2018; Solarin et al., 2017) and it is against the findings of Boamah et al. (2017). Our findings are similar to the result of (Boamah et al., 2017; Sikdar and Mukhopadhyay, 2018) and it is against the findings of Kumar et al. (2015) for India.

Table 6: Short run estimation from ECM

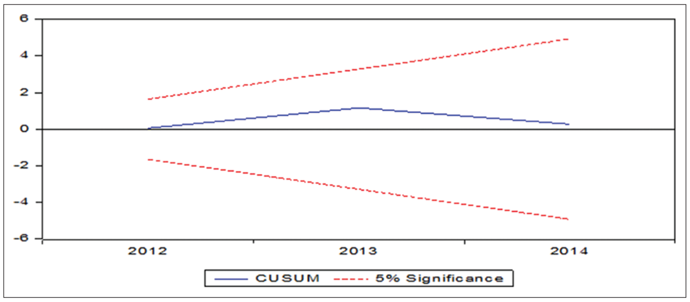
Dependent variable: GDP					
China			India		
Variable	Coefficient	t-Statistic	Variable	Coefficient	t-Statistic
D (LNTI)	0.3069**	3.7327	D (LNTI)	0.0037	0.4117
D (LNTI(-1))	−0.0930*	−2.2804	D (TO)	0.0000	0.0949
D (LNTI(-2))	0.1183*	2.8763	D (LNCO2)	−0.4071***	−4.0234
D (LNTI(-3))	−0.0627	−1.9701	CointEq(-1)	−0.0914*	−1.8376
D (LNTI(-4))	0.0689	1.2905			
D (LNTO)	0.2085**	3.7723			
D (LNTO(-1))	−0.0221	−0.3354			
D (LNTO(-2))	−0.3864**	−3.9855			
D (LNTO(-3))	−0.0890	−1.5055			
D (LNTO(-4))	0.0233	0.5362			
D (LNTO(-5))	0.1386*	2.2850			
D (LNCO2)	−0.5841*	−2.7379			
D (LNCO2(-1))	−0.4811	−2.0872			
D (LNCO2(-2))	1.1661**	3.3759			
D (LNCO2(-3))	−0.7497	−1.7745			
D (LNCO2(-4))	0.0668	0.1846			
D (LNCO2(-5))	−1.3493**	−3.7586			
CointEq(-1)	−0.8805**	−3.9207			

Source: Author's own calculation in Eviews.

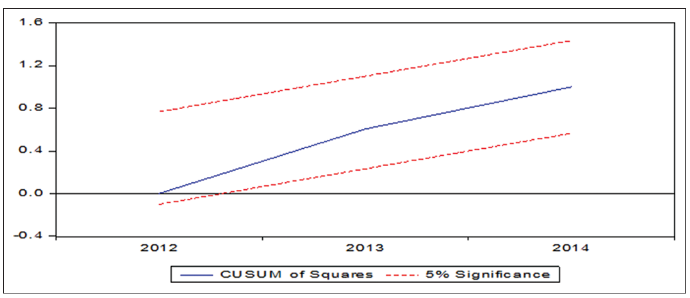
Table 7: Direction of Causality

China					India				
	lnGDP	lnTI	TO	$lnCO_2$		lnGDP	lnTI	TO	$lnCO_2$
lnGDP	---	4.7549	25.4469***	0.8527	lnGDP	---	1.2548	1.3882	24.8053***
lnTI	1.5674	----	19.2505***	8.7344**	lnTI	2.4222	----	8.7642*	23.1705***
TO	6.4122*	2.4861	----	5.5257	TO	4.0207	1.1676	----	15.7531***
$lnCO_2$	4.6152	7.6364**	16.2047***	---	$lnCO_2$	6.8233	0.5956	2.8495	---

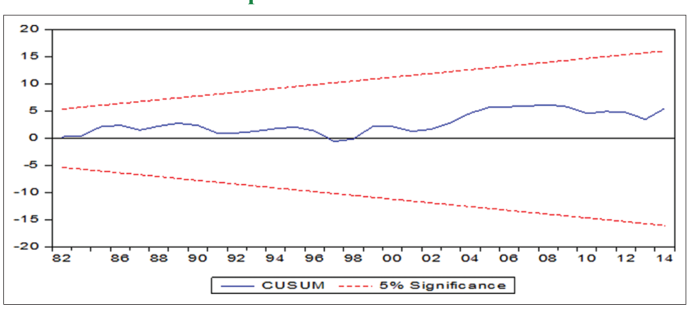
Graph 1: CUSUM test China



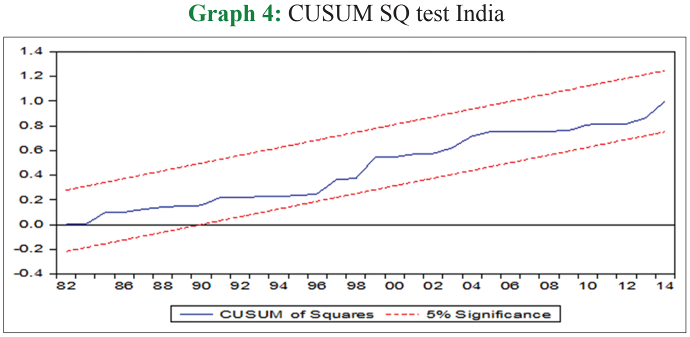
Graph 2: CUSUM SQ test China



Graph 3: CUSUM test India



Graph 4: CUSUM SQ test India



5. CONCLUSION AND POLICY IMPLICATION

China and India are the two largest transitional and developing economies of Asia. They remain in two distinctly different stages of structural change, technological innovation, trade, energy use, economic growth as well as different in culture and religious beliefs. The aim of this study is to investigate and compare the long and short run relationships between Technological innovation, Trade openness, CO_2 emission and Economic growth of China and India over the period of 1974-2016. We have applied the ARDL Bounds Test methodology and Toda-Yamamoto Granger Causality test in an augmented VAR framework with Zivot-Andrews structural break unit root test. The obtained results revealed that Technological innovation, Trade openness and CO_2 emission have a significant positive impact on Economic growth in the long-run but mixed effect in the short-run in China. For India, On the other hand, Trade openness and CO_2 emission have a significant positive impact in the long-run but CO_2 emission has a significant negative impact in the short-run on Economic growth. Technological innovation is not significant in the long run and both Technological innovation and Trade openness are not significant on Economic growth for India in the short run. Toda-Yamamoto Granger causality test reveals that bi-directional causality is running between Economic growth and Trade openness, between Technological innovation and CO_2 emissions as well as a unidirectional causality is running from Technological innovation and CO_2 emissions to Trade openness for China. On the other hand, our obtained results express that there is a unidirectional causality running from Economic growth, Technological innovation and Trade openness to CO_2 emissions as well as from Technological innovation to Trade openness for India. The obtained results from our study have important policy implication for China and India and they are illustrated as follows:

It is commented in the Global Competitiveness Report, 2017-18 that a good number of countries have the ability to innovate, but they have to do something more to enjoy the benefits. Major developing and emerging countries like China and India are becoming into the center for innovation as well as they are catching up with developed economies. Both the countries will be benefited from accelerating development in increasing the readiness of their people and industries to accept new technology. So, necessary steps should be taken by both the countries to spread innovation's potential for greater economic development and benefits of the country (Schwab).

Secondly, from our investigation, we found that trade openness has a significant positive impact on the Economic growth of both the countries in the long-run. It is creating new opportunities for making profits, the creation of jobs, establishing new industries through openness and overruling the negative effects of foreign competition. Both India and China should go for more trade openness by encouraging better institutional quality and efficient government interventions in the trade policy to keep up with the present economic growth.

Thirdly, Since Technological Innovation is not significant on Economic growth in the short-run as well as in the long run for India which reveals that Technological Innovation is not playing so expected role on the Economic growth of India as it is expected and should play. According to the discussion in the introduction section, the ranking of China and India in the Technological readiness and Innovation are 73 and 107 and 28 and 29 of respectively. This data reveals that India is competing with China in the Innovation sector but far away in the Technological readiness. It reveals that India remains far behind the world standard of technological progress. Taking all these things under consideration, Government of India should review the existing Technological 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.

Fourthly, one of the major impacts of technology would be on the environment. Since economic development is coming in these two countries but at the cost of environmental degradation. Still many industries are destroying the environment but the inclusion of green and clean technology in the harmful industries would improve the environmental quality of the countries as a whole. So Government of China and India should formulate the Technological Innovation policy which will increase the industrial growth refers economic growth of the country as a whole. More Government investment in R&D in the industrial sector and university-based research could improve this situation. China has improved in this sector recently but still has to go a long way, and India is far away from it.

Fifthly, since the use of energy, especially the fossil fuel is playing a crucial role in the economic development of both the countries; they can't reduce it overnight to decrease CO_2 emissions. So both the countries should go for the use of more renewable energy like solar energy, wind power, hydroelectricity, nuclear energy etc. The use of renewable energy will lessen the CO_2 emissions as well as maintain the present economic growth without hampering the environment. China has gained significant progress in the renewable energy sector but India is far behind it.

In the conclusion, it can be assumed that pro-economic growth Technological innovation, Trade, and energy use policy would strengthen the overall economic growth of the country, will exert a pull on the FDI, enhance the local and international trade, and expand the stock market which will ensure the balanced and stable growth of both the countries. In line with it, an adaptation of green and clean trade, Technology and energy use policy will play a strong role on harmful industries which will improve the environmental quality of the countries. From the policy perspective, any single or individual policy action in any macroeconomic variable like trade, Technology and use of energy will not bring any fruitful outcome. Therefore, an integrated macroeconomic policy will ensure the sustainable growth of China and India.

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APPENDIX

Appendix 1: Bai-perron multiple break dates and number of breaks

China				India			
lnGDP	lnTI	TO	$lnCO_2$	lnGDP	lnTI	TO	$lnCO_2$
1985	2002	1987	1993	1999	2003	2004	2004
1995	1998	1981	1984	1988	1995	1995	1985
2006	1992	2002	1999	2007	1985	1980	
	2010	1993	2009	1982			
	2006						

Source: Author's own calculation in Eviews