Technology-Intensive Trade, Economic Growth and CO2 emissions: ARDL Bounds Test Approach and Causality Analysis for BRICS

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Received: 9 December 2018 Accepted: 31 December 2018 Published: 15 January 2019

Abstract

This study identified long-run and short-run relationship as well as causal direction of medium and high tech (MHT) trade (proxy for tech-intensive trade), economic growth and CO2 emissions in BRICS for the period of 1992- 2015 applying ARDL bound test approach and error-correction based Granger causality. The disequilibrium (non-stationary) characteristics of CO2 emissions in China during 1992-2014, along with unavailability of MHT trade data prior to 1992, constrained the analysis of short-run and long-run relationship among the variables for the country. The study found that structural change did not affect CO2 emissions in India and Russia in the long-run but it did in the short-run in India. The study did not find any long-run cointegration among the variables for South Africa. It identified long-run causality running from MHT trade and growth to CO2 emissions for India and Russia, whereas long-run causality directed from MHT trade and CO2 emissions to growth was found in Brazil and India, and causality running from CO2 emissions and growth to MHT trade only held for India. The most critical policy suggestion provided by this study is that there is no generalized proposition when it comes to the nexus between MHT trade, economic growth and CO2 emissions.

Index terms— medium and high tech (MHT) trade; economic growth; CO2 emissions; brics; ARDL bound test; structural breaks.

1 Introduction

fter the instigation of Sustainable Development Goals (SDGs) as the successor of Millennium Development Goals (MDGs), the nexus between international trade, economic growth and Carbon dioxide emissions (Henceforth, trade-growth-CO2 emissions) has drawn significant research interests to academics and policy-makers alike. The 2030 Agenda for sustainable development acknowledges international trade as a pivotal mechanism for achieving a number of specific goals and targets of SDGs (Hoekman, 2016). According to Tipping and Wolfe (2015), as trade is the critical engine of economic growth and is highly related to each of the three dimensions of SDGs it has to be a part of coherent policy framework of sustainable development. Moreover, environmental degradation and climate change have been a significant concern for a sustainable world which is given a noteworthy focus in SDGs. Ever-growing CO2 emissions and other greenhouse gasses in the atmosphere are considered one of the key threats to environmental sustainability. As international trade results in higher economic growth and is considered as a vital tool for achieving SDGs, the effects of trade and economic growth on the environment is a critical research issue. Grossman and Krueger (1991), for instance, argued that the effects of trade on the environment can be explained in three different ways such as scale effect, technique effect, and composition effect. According to scale effect, growing trade upsurges global economic activities which consequently affects the environment. This effect of trade is "ceteris paribus" type that means the higher the international trade, the higher the global economic activities and environmental pollution considering other factors constant such as trade composition and technological progress. The technique effects suggest that growing foreign direct investment (FDI) and international trade in developing countries are accompanied with technology-based asset from developed to developing countries which in turn results in higher human capital accumulation and technological progress to the latter. These positive spill-over reduces pollution per output through technological innovation.

The composition effect argues that countries should master in production and export of the goods in which they enjoy a comparative advantage. Thus composition effect suggests a mixed effect of trade on the environment. This effect can be further explained by the pollution haven hypothesis (Copeland and Taylor (1994) which postulates that due to strict environmental regulations in developed countries pollution-intensive industries tend to establish in developing countries where environmental regulations are either non-existent or relaxed. Thus growing trade makes developing counties a pollution haven.

On the other hand, pollution halo hypothesis, proposed by Zarsky (1999), suggests that FDI and trade are accompanied with the transfer of environmentfriendly technological products and management from developed to developing countries which consequently results in environmental benefits for the latter.

Trade-growth-CO2 emissions nexus is best explained by environmental Kuznets curve (EKC), proposed by Kuznets (1955), providing a better understanding of the linkages between trade, economic growth and CO2 emissions. This hypothesis suggests an inverted U-shaped relationship. According to EKC, trade raises economic activity of a country which results in environmental degradation up to a threshold level. However, economic growth also increases per capita income of a country which raises the ability to invest in environment-friendly technology and better production process. Thus, after the threshold point economic growth reduces environmental pollution.

Having said this, this study aims at making several contributions to the literature pertaining to tradegrowth-CO2 emissions nexus. First, following the argument of technique effect and EKC hypothesis this paper takes technology intensive trade as a proxy of trade variable to identify the short-run and long-run relationship as well as casual direction as far as tradegrowth-CO2 emissions linkage is concerned. It verifies the proposition as to whether growing trade in medium and high-tech (henceforth, MHT) sectors reduces environmental pollution and raises economic growth, as suggested by EKC and technique hypothesis.

Second, rather than concentrating on single country or panel of countries this study focuses on country-specific linkages of trade-growth-CO2 emissions for BRICS, the acronym for an association of five major emerging economies: Brazil, Russia, India, China and South Africa. It provides policy insights as to whether the linkage and casualty are different across countries.

The motivation behind studying BRICS is that since 1990s these countries have been playing significant role in the world economy. Moreover, it is predicted that BRICS could play even greater role in decades to come. According to ??ilson and Purushothaman (2003), BRICS economies could become a much more substantial force of the world economy than G8 by 2050. Moreover, these economies passed through significant structural changes over the last few decades as far as GDP growth, share of world GDP and world trade are concerned. They are also becoming a major source of CO2 emissions. According to the Emission Database for Global Atmospheric Resources, while in the 1990s these economies constituted around 19% of global CO2 output in 2015 their share augmented to 43.7%. Along with higher economic growth these countries have witnessed the change in trade composition. Thus, identifying the nexus between trade, growth and CO2 emissions, this paper provides significant policy suggestions.

Methodologically this study contributes to different aspects of the literature concerning tradegrowth-CO2 emissions linkages. We identified reciprocal short-run and long-run relationship and casual direction among these variables based on three different models: CO2 as a function of MHT and growth, growth as a function of CO2 and MHT, and MHT as a function of CO2 and growth. We also identified long-run and shortrun relations as well as strong causalities for these variables. In this pursuit, an error-correction based unrestricted vector error correction model (UVECM) is employed to identify the reciprocal casual direction in different dimensions.

Second, in the analysis we strictly take into account the issue of structural break both in variables and in the model given its (structural break) growing importance. Moreover, EKC and technique effect hypothesis assume structural change or U-shaped relationship concerning the nexus between economic growth and CO2 emissions. We applied structural break unit root test to deal with structural break issues in stationary analysis. We also applied CUSUM and CUSUMSQ test to check the stability of the model and identify the break in the model.

The remainder of the study proceeds as follows. The next section reviews literature followed by section three that describes the data and variables used in this study.

Section four discusses econometric methodology. The results of the analysis are reported and discussed in section five. The last section draws conclusion and provides policy suggestions.

2 II.

3 Review of Literature

The literature concerning trade-growth-CO2 emissions nexus can be grouped into several strands. The first strand of literature focuses on the linkages between trade and economic growth. This field is rich in terms of academic work which is surveyed by several influential papers (Edwards, 1998;Giles & Williams, 2000a, 2000b;. The literature strongly supports the nexus between trade and economic growth. However, very few studies are conducted to identify the effects of trade composition of different sectors on economic growth. Mazumdar (1996)identified that pattern of trade is a crucial catalyst for economic growth. According to his findings, a country substantially gains from trade if it imports consumption good and exports capital good, although trade may not necessarily lead to higher economic growth. Lewer and Den Berg (2003) found similar results. . According to Lall (2000), low-technology products cause slower economic growth, whereas highly technology-intensive products result in rapid growth. Export growth in high tech sector contributes to output growth markedly when countries have a more significant share of manufacturing exports than the world average (Aditya & Acharyya, 2013).

The second strand of literature provides evidence on the economic growth-CO2 emissions nexus. This area is highly extensive, and a large number of studies have been conducted to identify the nexus between economic growth and CO2 emissions. An extensive literature on growth-CO2 emissions linkage focuses on environmental Kuznets curve (EKC) which postulates that the relationship between growth and CO2 emissions is inverted U-shaped. Antonakakis, Chatziantoniou, and Filis (2017)argued that although there exist an exhaustive list of studies in the field of growth-CO2 nexus, the findings of those studies are inconclusive and differ across countries or regions. The pioneer studies in this area focused on basic EKC model to identify the linkages between economic growth and CO2 emissions. Without identifying any explanatory factors studies suggest an inverted U-shaped relationship between these two variables (Beckerman, 1992;Dinda, 2004;Gani, 2012;Grossman & Krueger, 1991Heil & Selden, 2001; Moomaw & Unruh, 1997; Schmalensee, Stoker, & Judson, 1998). Moreover, several empirical studies have been performed to examine growth-CO2 nexus, and they identified Ushaped relationship as proposed by EKC model (Panayotou, 1993;Selden & Song, 1994;Stern, 2004).

On the contrary, a number of studies suggested an N-shaped EKC in the growth-pollution linkage (Grossman & Krueger, 1995;Shafik & Bandyopadhyay, 1992;Torras & Boyce, 1998). It is argued that in the preliminary stage of development there is a positive linkage between growth and environmental pollution, and the nexus becomes negative after a threshold level of economic growth. However, this relationship is reverted to positive after another turning point. This Nshaped relationship was further elaborated by several other studies (Álvarez-Herránz, Balsalobre, Cantos, & Alshehry and Belloumi (2015) for Saudi Arabia; Begum, Sohag, Abdullah, and Jaafar (2015) for Malaysia. However, these studies provide inconclusive and sometime contradictory results. It is fairly obvious from the review of existing literature that previous studies did not address several important aspects in identifying the nexus between trade, growth and CO2 emissions. International trade is the critical engine of economic growth and trade in general affects CO2 emissions via growth. Moreover, the 'composition effect' of trade proposed by **??**rossman and Kruger (1991) suggests that trade composition has a differential effect on CO2 emissions. Other notable studies such as (Aditya & Acharyya, 2013;Lall, 2000;Lewer & Den Berg, 2003;Mazumdar 1996) argued that trade composition affects economic growth of a country. As composition of trade affects growth, the linkages between economic growth and CO2 emissions could also have implications for the SKC hypothesis. These issues are overlooked by the studies mentioned above.

The third strand of literature concerns tradetechnology-CO2 emissions nexus. Grossman and Krueger (1991)argued that growing trade results in higher global economic activities which may cause environmental degradation implying that higher trade results in higher level of pollution. However, endogenous growth theories (Aghion & Howitt, 1990;Grossman & Helpman, 1991;Romer, 1990) suggest that the higher engagement of a country in international trade is accompanied with knowledge-based technology transfer in developing countries. Such technology transfer reduces pollution having positive effect on the environment. Zarsky (1999)argued that international trade has a beneficial effect on the environment in developing countries as international trade also brings environment-friendly technology in host countries. Moreover, some studies argued that technology obsolescence will turn EKC into N-shaped as after the second turning point the growth-CO2 nexus will be positive owing to the growing pollution from technology desuetude (Álvarez-Herránz et al. This study introduces several new issues to the existing literature of trade-growth-CO2 emissions nexus. It uses technology-intensive variables that involve trade of medium and high tech products followed by the identification of technology-intensive trade-growth-CO2 nexus. The variables used in the study address two critical effects of trade on the environment: 'technique effect' and 'composition effect'. The tech-intensive trade-CO2 emissions linkages could offer an important insight as to whether technological progress as represented by MHT trade reduces CO2 emissions. Moreover, the study offers another important insight as to whether trade composition has a differential effect on CO2 emissions as changes in MHT trade is associated with the transformation of trade composition of a country.. Moreover, rather than focusing on panel data or single country-based analysis, the study focuses on country-specific analysis for BRICS exploring as to whether tech-intensive trade-growth-CO2 emissions nexus differs across countries.

Although several studies focused on growth-CO2 emissions nexus and trade-growth-CO2 emissions nexus for BRICS **??**Azevedo et (Grossman & Krueger, 1991;Panayotou, 1993; **??**arsky, 1999).

4 III.

5 Data

The data for per capita CO2 emissions (in metric tons) and GDP growth were collected from the World Bank Development Indicators database of World Bank. We define technology-intensive trade as the export and import of medium and high tech (MHT) products. Technology-based classified data is not readily available. As the involvement of technology level in the production process as well as technology upgrading cannot be defined and measured fairly, it is pretty challenging to divide products based on technology intensity. Moreover, highly classified trade data based on technology-involvement is not available.

In this study, we followed technology based classification of products proposed by Lall (2000) and further applied by UNIDO (2014)andHatzichronoglou **??**1996). Lall (2000) classified products into four groups based on technology-intensity in the production process such as high tech (HT), medium tech (MT), low tech (LT) and primary products (PP) based on product classification of SITC rev 3. Lall (2000) defined high tech products that require advanced and fast-changing technology with greater investment in R&D. MT products also require complex technology with high concentration of R&D, technical skills and changing technology. The fundamental difference between MT and HT products is that MT products include those heavy low technology products that cannot be reallocated to low wage categories as well as high tech categories. The product wise classified data was collected from UNCOMTRADE database based on SITC rev 3 1 . Due to unavailability of classified trade data for the entire period, we considered a sample of 1996-2015 for Russia and 2000-2015 for South Africa. 1 The detail test of HT and MT products with their SITC number was provided in Appendix A. The summary statistics of variables (before taking log for MHT) are reported in Table 1 which shows a number of interesting trends. Russia has the highest per capita CO2 emissions followed by South Africa, China, Brazil and India (also see Figure **??**). However, change in CO2 emissions shows an entirely different scenario for the period 1992-2000. Brazil had the highest percentage increase in per capita CO2 emissions, whereas per capita emissions decreased markedly in Russia. However, from the beginning of 21 st century, the CO2 emissions skyrocketed in China, notably in the last one and a half decade.. China stands top in GDP growth followed by India (6.84%). However, growth is other three countries have been relatively low.

China had the highest average of MHT trade share followed by Russia, Brazil, India and South Africa. The change in MHT trade shows that in the period of 1992-2000 China witnessed the highest increase in its share, however, during 2000-2015; the highest increase was recorded for India.

IV.

6 Methodology a) Preliminary Analysis

This study applies ARDL (Autoregressive distributed lag) bound testing approach as proposed by Pesaran, Shin, and Smith (2001). Before applying ARDL approach, it is necessary to determine the order of integration of the variables using unit root test. The ARDL is applicable only for the variable that is stationary either at level or at first difference [I(0) or I(1)]. If any variable has an order of integration greater than one such as I(2), we cannot apply ARDL model for that variable as the critical bounds provided by Pesaran et al. (2001) are not valid for variables with the order of integration greater than one.

In this study, we applied three different types of unit root tests: (i) unit root test without structural break (ii) unit root test with one structural break (iii) unit root test with two structural breaks. Among the traditional unit root tests, we applied Augmented Dickey-Fuller (Dickey & Fuller, 1979) and Philips-Perron (Phillips & Perron, 1988) tests as these methods are are widely applied in time series analysis.

Traditional unit root tests (without structural break) assume that random shocks would only have temporary effects on the economy and would not affect long-run position. Nelson and Plosser (1982)argued that economic fluctuations are not temporary and random shocks have a permanent effecton economies. According to Perron (1989), traditional unit root tests such as ADF provide biased results towards the nonrejection of the null hypothesis of a unit root in the presence of structural break(s). Moreover, Barros, Gil-Alana, and Payne (2011)showed that variables such as energy, GDP, growth and CO2 emissions undergo structural changes , especially in emerging economies. Considering the significance of structural change in macroeconomic series, we applied both one structural break and two structural breaks unit root tests proposed by Lee and Strazicich (2013), and Lee and Strazicich (2003). These studies provide two models of structural break namely Model (A) known as crash model that allows change in intercept, and Model (C) known as trend model that allows a shift both in intercept and trend. Lee and Strazicich (2003)

7 b) ARDL Cointegration analysis

This study applies ARDL bound test approach due to its several advantages over other cointegration analysis such as Engle and Granger (1987), Johansen and Juselius (1990), and Johansen (1988). The most crucial advantage of ARDL approach is that it does not impose any restriction on the variables to be at the same order of integration. This model is applicable whether the variables are in same or different order of integration, whereas other cointegration approaches require the variables to be at same order of integration.

The ARDL approach is a two-step process for identifying the long-run and short-run relationship between variables of interest. First, we examine the existence of long-run cointegration among the variables used in the study. We then determine the long-run and short-run relationship among the variables using ARDL. The standard log-linear form of ARDL can be specified in three different ways:Model A Î?"CO2 t = ? t + ? ?? ?? ?1 ?? =1 j Î?"CO2 t-j + ? ?? ??1 ??=0 l Î?"Growth t-l + ? ?? ??1 ??=0 k Î?"logMHT t-k + ? 1 CO2 t-1 + ? 2 Growth t-1 + ? 3 logMHT t-1 + ? 1t ???????.. (1) Model B Î?"Growth t = ? t + ? ?? ?? ?1 ?? =1 j Î?"Growth t-j + ? ?? ??1 ??=0 l Î?"CO2 t-l + ? ?? ??1 ??=0 k Î?"logMHT t-k + ? 1 Growth t-1 + ? 2 CO2 t-1 + ? 3 logMHT t-1 + ? 2t ???????.. (2) Model C Î?"logMHT t = ? t + ? ?? ?? ?1 ?? =1 j Î?"logMHT t-j + ? ?? ???1 ??=0 l Î?"CO2 t-l + ? ?? ???1 ??=0 k Î?" Growth t-k + ? 1 logMHT t-1 + ? 2 CO2 t-1 + ? 3 Growth t-1 + ? 3t ???????.. (3)

Where, CO2, growth, and log MHT indicate CO2 emissions per capita (in metric tons), economic growth, and log of medium and high tech trade, respectively. Î?" and ? it are the first difference operator and white noise term respectively. m, p, q indicate the number of optimal lags of the variables. ARDL estimates (m+1) k number of regressions to obtain the optimal lag length of the variables where p and k are maximum lags and number of variables, respectively. We used Schwarz information criteria (SIC) to select appropriate lags for ARDL model as Pesaran et al. (2001) prefers SIC criteria for more parsimonious specifications (Ozturk & Acaravci, 2011).

The long-runcointegration of the variables is determined applying bounds test approach (using F-statistics or Wald coefficient diagnostic test). The null hypothesis of the bounds test assumes that there is no cointegration against the alternative hypothesis of the presence of long-run cointegration. Thus, the null hypothesis is for the three models can be reposted as follows: model A H 0 : ? r =0; H 1 : ? r ? 0; for model B: H 0 : ? r = 0; H 1 : ? r ? 0; for model C: H0: ? r = 0; H 1 : ? r ? 0 where r=1, 2, 3 for all the models. The null hypothesis is accepted or rejected based on the bounds test critical values provided by Pesaran et al. (2001). 2 Following the identification of long run cointegration, we estimate the short-run and long-run coefficients. The long-run ARDL model can be specified for the three models as follows:Year 2019 ( ) B CO2 t = ? t + ? ?? ???1 ?? =1 j CO2 t-j + ? ?? ???1 ??=0 l Growth t-l + ? ?? ???1 ??=0 k logMHT t-k + ? 1t ?????.. (4) Growth t = ? t + ? ?? ???1 ?? =1 j Growth t-j + ? ?? ???1 ??=0 l CO2 t-l + ? ?? ???1 ??=0 k logMHT t-k + ? 2t ????.. (5) logMHT t = ? t + ? ?? ???1 ?? =1 j logMHT t-j + ? ?? ???1 ??=0 l CO2 t-l + ? ?? ???1 ??=0 k Growth t-k + ? 3t ????.. (6)

The short-run relationship in ARDL model of the three models respectively is constructed as follows: **??**) **??**)Î?"CO2 t = ? t + ? ?? ?? ?1 ?? =1 j Î?"CO2 t-j + ? ?? ???1 ??=0 l Î?"Growth t-l + ? ?? ???1 ??=0 k Î?"logMHT t-k + aECT t-1 + ? 1t ????.. (Î?"Growth t = ? t + ? ?? ?? ?1 ?? =1 j Î?"Growth t-j + ? ?? ???1 ??=0 l Î?"CO2 t-l + ? ?? ???1 ??=0 k Î?"logMHT t-k + bECT t-1 + ? 2t ??.. (Î?"logMHT t = ? t + ? ?? ?? ?1 ?? =1 j Î?"logMHT t-j + ? ?? ???1 ??=0 l Î?"CO2 t-l + ? ?? ???1 ??=0 k Î?" Growth t-k + cECT t-1 + ? 3t ??.. (9)

Where, ECT is the error correction term that indicates whether the long-run relationship can be restored in the equilibrium point after an exogenous shock in the economy. a, b, and c are the coefficients of ECT for three different models representing the speed of adjustment which means how quickly the relationship converge to the equilibrium point following an exogenous shock. For underlying restoration of the equilibrium relationship, it is assumed that ECT should have statistically significant coefficient with a negative sign.

8 c) Stability Test

Although we identify the order of integration of the variables using one structural break and two structural break unit root test, there may exist multiple structural breaks in macroeconomic series due to structural change in the economy. Multiple breaks of the variables may question the stability of the model. For this purpose, we applied cumulative sum (CUSUM) and cumulative Sum of Squares (CUSUMSQ) tests to check the stability of long-run and short-run coefficients of ARDL model as proposed by Brown, Durbin, and Evans (1975). While Chow test mandates specified breakpoints, CUSUM and CUSUMSQ tests do not require previously known break points. They plot graph of cumulative sum of residuals and cumulative sum of squares of the residuals of coefficients. All points on graph should remain within the critical bounds at 5% level. If any point on graph crosses the critical bound, the model is not stable and there might have break(s) in the model. We should use dummy variables to make the model stable.

9 d) Granger causality

The ARDL model determines the existence of long-run cointegration as well as estimates short-run and long-run relationship among variables but it does not identify the direction of causality between variables. To identify the causal direction, we applied error correction based Ganger causality using unrestricted VECM model: **??**0) **??**1)Î?"CO2 t = ? t + ? ?? ?? ?1 ?? =1 j Î?"CO2 t-j + ? ?? ???1 ??=0 l Î?"Growth t-l + ? ?? ???1 ??=0 k Î?"logMHT t-k + a 1 ECT t-1 + ? 1t ??.. (Î?"Growth t = ? t + ? ?? ?? ?1 ?? =1 j Î?"Growth t-j + ? ?? ???1 ??=0 l Î?"CO2 t-l + ? ?? ???1 ??=0 k Î?"logMHT t-k + a 2 ECT t-1 + ? 2t ??.. (Î?"logMHT t = ? t + ? ?? ?? ?1 ?? =1 j Î?"logMHT t-j + ? ?? ???1 ??=0 l Î?"CO2 t-l + ? ?? ???1 ??=0 k Î?" Growth t-k + a 3 ECT t-1 + ? 3t ?.. (12)

Where, ? it is independently and normally distributed residuals with a mean zero and a constant variance. ECT is the error correction term that indicates the restoration of equilibrium relationship. ?, ?, a, b, and c are the parameters to be estimated. The coefficients of the ECT indicate the speed of adjustment of the equilibrium relationship following any exogenous shock in the economy. We selected appropriate lags using SIC. we identified Granger causality in three different ways for each equation.

Short run or weak granger causality is detected using null hypothesis: (i) H 0 : ? r =0 (ii) H0: ? r =0 (iii) H0: ? r = ? r = 0 for all three equations where r=1,2, 3 Long run causalities are determined by testing the hypothesis : H 0 : a r =0 where r=1,2,3

Strong causalities are determined using the null hypothesis; H 0 : ? r = a r =0 (ii) H 0 : ? r = a r =0 (iii) H 0 : ? r = ? r = a r =0 where r=1, 2, 3 for all three equations.Year 2019 ( ) B V.

10 Results and Analysis

We started off the analysis checking the time series properties of the variables using unit root test. One structural break and two structural breaks LM unit root test results (Table 5 and 6) evidence that both economic growth and logMHT variables are stationary at first difference. However, CO2 emissions variable is non-stationary in all cases for China, but it is stationary at first difference for other countries.

As ARDL bound test approach of cointegration requires that the variables should be either I(0) or I(1), we have to drop China for the analysis of tech-intensive trade-growth-CO2 emission linkage and causality. We can apply the ARDL model for other four countries. The bound tests results along with other diagnostic tests are reported in Table 7. The bound test results suggest that for model A there is no long-run cointegration for Brazil and South Africa. As far as model B is concerned, there exists long-run cointegration for Brazil, India and Russia but this does not hold true for South Africa. Model C also confirms that there exists long-run cointegration for Brazil, India, and Russia but again not for South Africa. So, based on bounds tests results we dropped South Africa for further analysis (and also skipped model A for Brazil).

As Bai-Perronbreak point test evidenced multiple breaks in our variables of interest, we checked the stability of short-run and long-run coefficients of ARDL model using CUSUM and CUSUMSQ tests. These tests found structural break for model A for India and Russia in 2007 and 2009, respectively, whereas the estimated parameters are stable for all other cases. 3 Due to the presence of structural break, we used a dummy variable for model A involving India and Russia. The CUSUM and CUSUMSQ test results suggest that both the ARDL estimates with dummy variables are stable. 4

11 a) ARDL short-run and long-run estimates

The long-run ARDL estimation results are reported in Table 8. As far as model A is concerned, it is evident that MHT trade has significant positive 3 CUSUM and CUSUMQ test results are provided in Appendix B. 4 CUSUM and CUSUMQ test results including dummy variable for Model A for India and Russia are provided in Appendix C. association with CO2 emissions both in India and Russia. While growth does not affect CO2 emissions significantly, there exists negative asociation. The statistically insignificant coefficients of the dummy variables evidence that the structural break does not significantly affect CO2 emissions in the long-run.

In case of model B, the long run estimates suggest that MHT trade significantly affects economic growth of India and Brazil, whereas the association between these two variables is negative pertaining to Russia. CO2 emissions have a significant effect on growth for India whereas for Brazil and Russia the effect is insignificant. Year 2019 ( ) B

12 We exclude ARDL estimation of model A for Brazil and of all models for South Africa as bounds test did not find any long run cointegration for these models.

The results pertaining to model C also suggest that growth has a significant positive association with MHT trade indicating that higher growth substantially raises MHT trade. CO2 emissions raise MHT trade markedly in case of India and Russia, whereas there is a negative association when it comes to Brazil.

13 "D" indicates the difference operator and "(-)" means the lag number of differenced operator. The numbers are reported in two decimal points. "Cointeq (-1)" indicates the error correction term (ECT).

The short-run ARDL estimation results are summarized in Table ??. It is generally assumed that the value of error correction term should fall in the range of 0 to -1. However, several studies (Narayan & Smyth, 2006; Samargandi, Fidrmuc, & Ghosh, 2015) reported the range of ECT value could be in the range of 0 to -2. For model A, the results show that ECT has a statistically significant negative sign indicating that the long run relationship of Model A can be adjusted to the equilibrium level following any shock. The speed of adjustment is found to be higher for Russia (98%) than India (16.59%). In both cases, MHT trade contributes to restoration of imbalances. Structural change as indicated by dummy variable markedly affects the relationship in short-run in case of India.

As far as model B is concerned, the ECT is statistically significant at 1% level for all the countries but the value is lower than -1. Narayan and Smyth (2006)argued that when ECT value ranges from -1 to -2 it produces dampen fluctuation in the relationship on the equilibrium path. The short-run results show the values of ECT are -1.288, -1.50, and -1.004 for Brazil, India, and Russia, respectively. This infers that instead of monotonically converging to the equilibrium path directly, the process of error correction vacillates around the long run value in a blunting way. When the process is complete, the ECT converge to equilibrium point hastily (Narayan & Smyth, 2006). MHT trade has a significant positive impact in the restoration of underlying imbalances for India and Brazil, whereas its impact is not significant for Russia. CO2 emissions have significant positive effect for Russia whereas the reverse is true for India.

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The results concerning model C show a statistically significant negative signs for Brazil (.054) and Russia (-.17). So, this long-run relationship can be significantly restored to the equilibrium point following any shock in the economy. However, for India ECT shows a positive sign which is statistically significant at 1% level. Model C for India does not suffer from serial correlation or heteroscedasticity problem and appropriate lags of ARDL model was selected based on SIC. Moreover, we also checked the stationarity of the variables using one and two structural break unit root tests. So, this significant positive coefficient of ECT implies that owing to any structural change or exogenous shocks on the variables the long-run relationship will be diverged from the equilibrium.

The ARDL bounds test approach identifies the presence of long-run cointegrationas well as estimates short-run and long-run relationship but it does not determine the causal direction between the variables. To identify the direction of causality we applied UVECM based ganger causality test.

15 b) Granger causality results

The causality test results reported in Table 10 suggest that there exists long-run causality running from logMHT and growth to CO2 emissions both for India and Russia. This outcome supports the theoretical view that higher economic growth and growing trade in MHT sector could lead to the rise of CO2 emissions. The long-run causality derived from MHT and CO2 emissions to growth holds for India and Brazil, whereas causality from CO2 emissions and growth to LogMHT only exists for India. So, the view that growing MHT trade and CO2 emissions cause higher economic growth holds for Russia and India, whereas CO2 and growth cause higher level of trade in MHT in case of India. The short-run causality test results reported in Table 11 indicate that growth and MHT trade individually as well as jointly cause CO2 emissions for India, whereas no causality runs from CO2 and MHT to growth. However, growth causes MHT trade significantly in India. In case of Russia, there exists only short-run causality directed from MHT trade to growth. For Brazil, CO2 emission causes growth and MHT trade in the short run.

16 VI. Conclusion and Policy Implication

Brazil whereas this contribution is 51.72% and 34.33% in India and Russia, respectively. MHT trade contributes 58.36% and 30.99% to growth variance in Russia and India, whereas the contribution of MHT trade to growth is negligible in Brazil. The percentage of variance of MHT trade from its own is a maximum of 98.54% in Russia and followed by 39.34% and 18.06% in Brazil and India, respectively. The contribution of other two variables to MHT trade variance is negligible in Russia, whereas CO2 emissions contribute more than 50% in other two countries.

Considering the growing concerns regarding environmental degradation and importance of trade and economic growth in achieving SDGs this study identified the long-run and short-run relationship as well as causal direction for tech-intensive trade, economic growth and CO2 emissions in BRICS for the period of 1992-2015.

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The study offers a number of important findings making contribution to the literature on the nexus between trade, economic growth and CO2 emissions. First, there is a constraint to establish linkages among these variables pertaining to China as CO2 emissions variable is nonstationary both in level and first difference. Nevertheless, this also suggests that CO2 emissions in china have been subject to marked structural change in the last two and a half decades.

As far as South Africa is concerned, the study did not find any long-run cointegration among the variables suggesting that none of the variables significantly affects each other in the long-run. This indicates that CO2 emissions are not the results of economic growth or high trade in MHT in this country. For Brazil, there is no long-run cointegration running from MHT trade and economic growth to CO2 emissions. This infers that CO2 emissions are not caused significantly by MHT trade or economic growth or both.

Moreover, the study found several structural breaks in the variables in question, especially in CO2 emissions and MHT trade that had been subject to structural change in the last few decades. This is a key finding of this study is also backed by Barros et al. (2011) who argued that energy variables showed several structural breaks in emerging economies. Our study also provides policy suggestions whether these structural breaks show significant effect or not. It is found that structural change did not affect CO2 emissions in India and Russia in the long-run but it affected CO2 emissions in India in the short-run.

The findings suggest that MHT trade significantly led to the rise of CO2 emissions in India and Russia both in the short-run and long-run. For these counties it was found that growing trade in MHT trade had significant contribution to rise in CO2 emissions. Growing trade in MHT trade significantly raised economic growth in India and Brazil both in the long-run and short-run. However, both CO2 emissions and growth affected MHT trade markedly in the long run. Granger causality results evidence that MHT trade and growth significantly caused CO2 emissions in India and Russia in the long run, whereas long-run causality running from MHT trade and CO2 to growth holds true for Brazil and India, and causality from CO2 and growth to MHT trade prevailed only for India. Short run and strong causalities aroused from growth to CO2 and MHT to CO2 in India, whereas CO2 emissions caused growth and MHT in Brazil. MHT trade and growth causality directed from growth to MHT existed for India, whereas the causality direction was found opposite for Russia.

The most critical policy suggestion provided by this study is that there is no generalized hypothesis or proposition when it comes to the nexus between medium and high tech trade, economic growth and CO2 emissions. As our study evidenced, these variables have differential effects and causal direction between them. From this analysis, we can infer that although BRICS represents the economic dynamism of emerging markets, there is marked diversity among these economies. This is largely owing to structural change these economies have been undergoing, reflected in three variables that we have analyzed. Thus, policymakers dealing with issues pertaining to tradegrowth-CO2 emissions nexus in light of SDGs, in particular, and growth and sustainability trade-off, in general, should take these factors into account while they devise policies. It is advisable to rely on country specific study vis-à-vis studies are conducted on panel of countries.

The exclusion of China from our analysis due to non-stationary characteristics of CO2 emissions data can be considered as a drawback of this study. Nevertheless, it is also an important research finding that the nexus between MHT trade, economic growth and CO2 emissions for China can be studied further using other econometric methods. Moreover, future studies should further disaggregate trade data based on technology intensity as to identify which category of products cause maximum (minimum) economic growth generating minimum (maximum) amount of greenhouse gases.

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Figure 1:

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Figure 2: Table 9 :

1

		China	Brazil	India	Russia	South Africa
CO2	Mean	4.34	1.89	1.12	11.48	8.83
	Maximum	7.55	2.59	1.73	13.97	10.0
	Minimum	2.30	1.42	0.77	10.1	7.77
	Std. Dev.	1.91	0.29	0.28	0.95	0.60
	Change %					
	1992-2000	16.77	31.03	26.99	-23.98	8.04
	2001-2014	175.11	36.66	78.03	11.13	10.16
	Observations	23	23	23	23	23
GROWTH	Mean	10.01	2.79	6.84	1.05	2.71
	Maximum	14.23	7.52	10.25	10.00	5.60
	Minimum	6.90	-3.76	3.80	-14.53	-2.13

Figure 3: Table 1 :

2

	Series in level											
	ADF (Intercept)			ADF (Intercept & trend)			PP (Intercept)			PP (Intercept & trend)		
	CO2	Growth	Log MHT	CO2	Growth	Log MHT	CO2	Growth	Log MHT	CO2	Growth	Lo[illegible] M[illegible]
China	0.949	1.87	1.548	2.597	1.87	0.122	.796	1.92	1.35	1.57	- 1.95	0.6
Brazil	.694	3.77***	2.02	0.561	3.69**	2.78	.796	3.81***	1.92	0.73	- 3.71**	1.3
India	.012	3.89***	1.08	0.47	4.08**	3.048	.83	3.82***	1.719	0.25	- 4.02**	2.0
Russia	3.07**	2.95**	0.88	3.99**	2.489	1.419	2.97**	2.95**	0.88	7.19***	- 2.26	1.4
South Africa	2.289	3.90***	1.75 6	2.30	3.67**	0.796	2.31	3.90***	2.165	2.38	- 3.68**	0.2

*[Note: Note: The table reports ADF and PP unit root test results in intercept as well as intercept and trend. The numbers of optimal lags are based on Schwarz Information Criterion (SIC). ***; **; and * indicates rejection of null hypothesis of unit root at 1%; 5%; and10% significance level respectively.The numbers are reported in two decimal points.]*

Figure 4: Table 2 :

1 2 3 4

[1]If the calculated F-statistics is higher than the upper bound critical value then we can reject the null hypothesis of no cointegration suggesting that there exists long-runcointegration among the variables.

[3]The results of variance decomposition tests are provided in appendix D

[4]Note: Plot of CUSUM and CUSUMQ tests for the parameter stability from ARDL models with dummy variable. The straight lines represent critical boundaries at 5% significance level.

3

	ADF (Intercept)			Series in First difference ADF (Intercept & Trend)		
	CO2	Growth	LogM HT	CO2	Growth	LogM HT
China	-1.505	-4.16***	-2.86*	-1.18	-4.08**	-3.03
Brazil	-4.42***	-5.48***	-3.09**	-4.56***	-5.57***	-3.39*
India	-0.783	-5.24***	-3.19**	-4.94***	-5.08***	-3.39*
Russia	-3.23**	-6.62***	-3.22**	-3.207*	-5.07***	-3.11
South Africa	-4.58***	-5.19***	-3.24**	-4.51***	-5.17***	-3.96**

) (B With regard to Russia and India the variable shows conflicting results. AsPerron (1989) argued that trad

*[Note: * Note: The table reports ADF and PP unit root test results in intercept as well as intercept and trend. The numbers of optimal lags are based on Schwarz Information Criterion (SIC). ***; **; and * indicates rejection of null hypothesis of unit root at 1%; 5%; and 10% significance level respectively.The numbers are reported in two decimal points.]*

Figure 5: Table 3 :

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Country	CO2 emissions		Growth		LogMHT	
	No. of Breaks	Break date(s)	No. of Breaks	Break date(s)	No. of Breaks	Break date(s)
China	3	2006;2010;2003	1	1995	3	2003;2007;1999
Brazil	2	2010;1996	0		3	2005;1995;2008
India	5	2008;1999;1996;2012; 2005			5	2005;2008;2011;1995; 2002
Russia	0		3	1999;1995;2009	1	2005
South Africa	1	2004	0		2	2005;2010

Notes: The calculated F-statistic of break tests is significant at 5% level as provided by Bai-Perron (Econom
critical values.

Figure 6: Table 4 :

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Country	Trend Break Model (in level)			Crash Model (in level)			Trend Bre	
	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	G
China	-2.09	-2.40	-2.24	-0.82	-1.58	1.26	-3.01	-4.
Brazil	-2.31	-5.22***	-1.99	-1.32	-5.10***	-1.96	-7.42***	-7.
India	-4.03	-4.44**	-1.87	-1.41	-4.43**	-1.99	-5.35***	-6.
Russia	-3.35	-5.35	-2.93	-1.16	-3.41	-1.43	-4.68***	-6.
South Africa	-2.73	-3.40	-3.14	-2.60	-3.33	-1.85	-5.20***	-5.

Note: Crash Model allows for a change in level Trend Break Model allows for changes in level and slope of t
lag structure is chosen following a general-to-specific approach starting with max 12 lags. The critical values
Strazicich (2003). We conducted the estimation and tests using RATS 9.2. ***; **; and * indicates rejection
at 1%; 5%; and 10% significance level respectively. The numbers are reported in two decimal points.

Figure 7: Table 5 :

6

	Trend Break Model (in level)			Crash Model (in level)			Trend Break Model (at first difference)			Crash Model (at first differen
Country	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growt
China	-2.84	-4.95	-3.48	-0.86	-1.83	-1.3723	-3.89	-7.01***	-5.36	-1.97	-4.97**
Brazil	-4.54	-6.32**	-2.79	-1.47	-5.46***	-2.1607	-7.76***	-8.28***	-6.07**	-6.89***	-6.04**
India	-4.91	-5.04	-3.22	-1.65	-4.60***	-2.1783	-8.58***	-6.82**	-10.68***	-4.91***	-6.63**
Russia	-4.17	-5.11	-3.66	-1.24	-4.80***	-1.60	-5.39*	-8.76***	-9.91***	-4.63***	-6.27**
South Africa	-4.26	-4.50	-3.91	-2.85	-3.57	-2.26	-6.25**	-5.31*	-6.02*	-5.98***	-5.07**

*[Note: Note: Crash Model allows for a change in level Trend Break Model allows for changes in level and slope of the trend. The optimal lag structure is chosen following a general-to-specific approach starting with max 12 lags. The critical values are fromLee and Strazicich (2003). We conducted the estimation and tests using RATS 9.2. ***; **; and * indicates rejection of the null of a unit root at 1%; 5%; and 10% significance level respectively. The numbers are reported in two decimal points.]*

Figure 8: Table 6 :

7

	Model A, CO2=f(Growth, LogMHT)				Model B, Growth=f(CO2, LogMHT			
Country ?	Model ?	F ?	LM ?	HET ?	Model	F	LM	HET
Brazil	(4, 4, 4)	2.499	1.37	0.65	(1, 0, 1)	44.55**	0.893	1.86
India	(2, 0, 0)	4.44***	7.82**	14.06**	(2, 0, 0)	7.195**	1.374	0.18
Russia	(2, 2, 0)	15.64***	1.541	12.39	(1, 0, 1)	15.42***	0.537	1.02
South Africa	(1, 2, 2)	2.479	0.98	4.516	(2, 1, 1)	1.506	3.944	10.1

? As per CUSUM and CUSUMQ tests structural break occurs for model A in 2007 and 2009 for India and I
Dummy variables are used in ARDL models for these countries for model A. ***; **; and * indicates signific

[Note: and 10% respectively. The numbers are reported in two decimal points.? We exclude China from the analysis due to non-stationary characteristics of CO2 variable in China. ? F indicates the ARDL cointegration test using Wald test F-statistics. The critical values for the lower I(0) and upper I(1) bounds are taken fromNarayan (2005) ? LM is the Lagrange multiplier test for serial correlation with a ? 2 distribution with only one degree of freedom. ? HET is test for heteroskedasticity with a ? 2 distribution with only one degree of freedom.]

Figure 9: Table 7 :

8

	CO2=f (Growth, LogMHT)		Growth=f (CO2, LogMHT)			LogMHT = f (Growth, CO2)	
			CO2	-0.336		Growth	0.60*
Brazil			logMHT	1.85**		CO2	-0.308
?							
			C	-17.17**		C	10.19***
	Growth	-0.017	CO2	-6.518**		Growth	0.04*
India	logMHT	0.61***	logMHT C	5.14**	-	CO2 C	1.35***
	Dum	0.36		40.42***			8.56***
	C	-5.05**					
	Growth	-0.006	CO2	4.73		Growth	0.098**
Russia	logMHT	1.66***	logMHT C	-11.92**		CO2 C	0.73*** 2.47
	Dum	0.18		78.80**			
	C	-6.84**					

*[Note: Note: ***; **; and * indicates significance level at 1%; 5%; and 10% respectively. Dum indicates the dummy variables. The numbers are reported in two decimal points. ?]*

Figure 10: Table 8 :

10

Country	CO2	Growth	LogMHT
Brazil		7.76**	0.64
India	21.38***	18.22***	5.33***
Russia	5.20**	2.27	0.61

Note: ***; **; and * indicates the rejection of null hypothesis at 1%; 5%; and 10% significance level respecti Granger causality analysis for model A for Brazil and for all models for South Africa as bounds test did not cointegration for these models.

Figure 11: Table 10 :

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Direction of causality	Short Run Causality	Brazil India	Russia	Str
Growth?CO2		4.95**	0.48	
LogMHT ? CO2		3.31*	0.73	
Growth, LogMHT ? CO2		3.00*	0.52	
Dummy ? CO2		10.70***	1.40	
CO2? Growth	6.10**	2.05	0.59	10.
LogMHT ? Growth	3.12*	0.13	3.30*	4.0
CO2 , LogMHT ? Growth	5.45**	1.05	1.92	7.3
CO2? LogMHT	6.09**	1.13	1.05	4.0
Growth ? LogMHT	0.35	4.78***	0.75	0.4
CO2 , Growth ? LogMHT	3.15**	2.82*	0.74	2.5

Note: ***; **; and * indicates the rejection of null hypothesis at 1%; 5%; and 10% significance level respe indicates direction of causality.

It is also reported in Table 11 that both growth and MHT trade strongly causes CO2 emissions in India, whereas growth strongly causes MHT trade. For Russia, strong causality runs from MHT trade to growth. However, in case of Brazil, both CO2 emissions and MHT trade have strong causal effect on growth, whereas CO2 emissions cause MHT trade. Dummy variable has strong causality to CO2 emissions in Russia.

To check the robustness of causality analysis we used variance decomposition approach as proposed by several studies (Shahbaz, Hye, Tiwari, & Leitão, 2013; B. Wang & Wang, 2017). The variance decomposition results 5 indicate that the share of CO2 emissions explained by the external factors not included in the model are 83.35% and 31.14% in India and Russia, respectively. The share of growth and MHT trade in CO2 emissions are 12.26% and 2.19% in India, and 21.37% and 4.87% in Russia, respectively. Structural change represented by the dummy variable

contribute to CO2 emissions of 42.(contribution is very low (2.18%) in growth due to its own shock is max

Figure 12: Table 11 :

.1 Acknowledgements

The authors acknowledge the contribution of anonymous reviewer and the PhD fellows for enriching the article. Moreover, the authors are grateful to the supervisor Md. Shohidul Islam for improving the language of the final manuscript.

.2 Funding

The research was conducted by authors own finance.

.3 Availability of data and materials

All the data and relevant material are available to corresponding author. For any research purpose, he will send the data in excel format through email upon request.

.4 Appendix B: CUSUM and CUSUMSQ test results

.5 Model

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