Volume 19 Issue 39
Originally issued as B6



Global Journal of Management and Business Research: B
Economics and Commerce
Volume 19 Issue 6 Version 1.0 Year 2019
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4588 & Print ISSN: 0975-5853

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

GJMBR-B Classification: JEL Code: F43



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

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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.

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

I. Introduction

After 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 environment-friendly 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),

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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 trade-growth- 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 trade-growth- 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 Wilson 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 trade-growth-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 short-run 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.

II. 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; Lewer & Berg, 2003). 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

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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, 1991, 1995; Heil & Selden, 2001; Moomaw & Unruh, 1997; Schmalensee, Stoker, & Judson, 1998). Moreover, several empirical studies have been performed to examine growth-CO2 nexus, and they identified U-shaped 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 N-shaped relationship was further elaborated by several other studies (Álvarez-Herránz, Balsalobre, Cantos, & Shahbaz, 2017; Johansson & Kriström, 2007; Lorente & Álvarez-Herranz, 2016) suggesting that the second turning point of the positive relationship between growth and pollution occurs due to technology obsolescence that reemerges the 'scale effect' of growth on the environment.

A number of studies analyzed the growth-CO2 emissions nexus using panel data models (Al-Mulali & Sab, 2012; Azam, 2016; Balsalobre-Lorente, Shahbaz, Roubaud, & Farhani, 2018; Heidari, Katircioğlu, & Saeidpour, 2015; Holtz-Eakin & Selden, 1995; Narayan & Narayan, 2010; Ozcan, 2013; Özokcu & Özdemir, 2017; Richmond & Kaufmann, 2006; Salahuddin & Gow, 2014; Salahuddin, Gow, & Ozturk, 2015; Sebri & Ben-Salha, 2014; S. Wang, Li, & Fang, 2017). Most of these studies, nevertheless, offer inconclusive results. However, Azevedo, Sartori, and Campos (2018) found that the effects of economic activity on the environment is at best mixed and growth-environment pollution nexus should be identified on country basis or case-by-case basis. A vast number of papers also identified the growth-CO2 emissions nexus studying specific country. They include, Chang (2010) and Long, Naminse, Du, and Zhuang (2015)for China; Ozturk and Acaravci (2010) for Turkey, Alam, Begum, Buysse, and Van Huylenbroeck (2012) for Bangladesh; Jayanthakumaran, Verma, and Liu (2012) and Govindaraju and Tang (2013) for China and India, Farhani, Chaibi, and Rault (2014) for Tunisia, Yang and Zhao (2014) for India, 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 Grossman 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 trade-technology-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., 2017; Johansson & Kriström, 2007; Lorente & Álvarez-Herranz, 2016).

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

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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 al., 2018; Cowan, Chang, Inglesi-Lotz, & Gupta, 2014; Pao & Tsai, 2010, 2011; Sebri & Ben-Salha, 2014), those studies did not address some significant issues. Most of the studies on BRICS, for instance, identified trade-growth-CO2 emissions linkages using panel data models (Cowan et al., 2014; Pao & Tsai, 2010, 2011), whereas Azevedo et al. (2018) argued that environmental effects of trade and growth is mixed and must be looked into country-specific perspectives. Azevedo et al. (2018)focused on country-specific analysis, but the study did not consider the effects of technology-intensive trade on the linkages between trade, growth and CO2 emissions. However, trade statistics shows that these economies notably China, India and Brazil experienced a substantial increase in medium and high tech trade over the last two and a half decades. Moreover, none of the previous studies examined the effects of MHT trade on growth and CO2 emissions. Nevertheless, several studies reported that trade composition has differential effects on growth (Aditya & Acharyya, 2013; Lall, 2000; Lewer & Den Berg, 2003; Mazumdar 1996) as well as on the environment(Grossman & Krueger, 1991; Panayotou, 1993; Zarsky, 1999).

III. 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.

Table 1: Summary statistics

		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 2001-2014	 16.77 175.11	 31.03 36.66	 26.99 78.03	 -23.98 11.13	 8.04 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

[1] The detail test of HT and MT products with their SITC number was provided in Appendix A.

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	Std. Dev.	2.22	2.55	1.99	6.92	1.91
	Observations	24	24	24	24	24
MHT	Mean	8.39E+11	8.77E+10	7.26E+10	1.04E+11	4.59E+10
	Maximum	5.51E+11	1.82E+11	1.83E+11	2.28E+11	7.32E+10
	Minimum	2.15E+12	2.03E+10	8.25E+09	2.14E+10	1.84E+09
	Std. Dev.	6.51E+10	5.46E+10	6.82E+10	7.59E+10	2.22E+10
	Change % 1992-2000	238.68	148.77	101.23		
	2001-2014	733.67	158.62	905.42	377.01	190.37
	Observations	7.72E+11	24	24	20	17

Note: The MHT trade data covers period of 1996-2015 for Russia and 2000-2015 for South Africa. MHT Trade figures are in US$ and CO2 emissions are in metric tons per capita.

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 1). 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 21st 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. 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 non-rejection 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)argued that ADF type endogenous break unit root test (Clemente, Montañés, & Reyes, 1998; Lumsdaine & Papell, 1997; Zivot & Andrews, 2002) are subject to size distortions and causes too much rejection of null hypothesis. They also estimate that break incorrectly leading to spurious rejection of null hypothesis (Lee & Strazicich, 2003; Ozturk & Acaravci, 2011; Vogelsang & Perron, 1998). The minimum Lagrange Multiplier (LM) unit root test (Lee & Strazicich, 2003, 2013) endogenously identifies structural breaks as well as avoids size distortion and spurious rejection of unit root with structural break(s).

b) ARDL Cointegration analysis

This study applies ARDL bound test approach due to its several advantages over other cointegration

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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:

$$Model\ A \Delta CO2_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta CO2_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta Growth_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + \delta_1 CO2_{t-1} + \delta_2 Growth_{t-1} + \delta_3 logMHT_{t-1} + \varepsilon_{1t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Model\ B \Delta Growth_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta Growth_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + \gamma_1 Growth_{t-1} + \gamma_2 CO2_{t-1} + \gamma_3 logMHT_{t-1} + \varepsilon_{2t} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$Model\ C \quad \Delta logMHT_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta logMHT_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta Growth_{t-k} + \omega_1 logMHT_{t-1} + \omega_2 CO2_{t-1} + \omega_3 Growth_{t-1} + \varepsilon_{3t} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

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. Δ and ε_{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: $\delta_r=0$; H_1: $\delta_r \neq 0$; for model B: H_0: $\gamma_r= 0$; H_1: $\gamma_r \neq 0$; for model C: H0: $\omega_r= 0$; H_1: $\omega_r \neq 0$ 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:

$$CO2_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j CO2_{t-j} + \sum_{l=0}^{p-1} \varphi_l Growth_{t-l} + \sum_{k=0}^{q-1} \lambda_k logMHT_{t-k} + \varepsilon_{1t} \ldots\ldots\ldots\ldots (4)$$

$$Growth_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j Growth_{t-j} + \sum_{l=0}^{p-1} \varphi_l CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k logMHT_{t-k} + \varepsilon_{2t} \ldots\ldots\ldots\ldots (5)$$

$$logMHT_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j logMHT_{t-j} + \sum_{l=0}^{p-1} \varphi_l CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k Growth_{t-k} + \varepsilon_{3t} \ldots\ldots\ldots\ldots (6)$$

The short-run relationship in ARDL model of the three models respectively is constructed as follows:

$$\Delta CO2_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta CO2_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta Growth_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + aECT_{t-1} + \varepsilon_{1t} \ldots\ldots\ldots\ldots (7)$$

$$\Delta Growth_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta Growth_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + bECT_{t-1} + \varepsilon_{2t} \ldots\ldots\ldots (8)$$

$$\Delta logMHT_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta logMHT_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta Growth_{t-k} + cECT_{t-1} + \varepsilon_{3t} \ldots\ldots\ldots (9)$$

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.

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

[2] 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.

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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.

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:

$$\Delta CO2_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta CO2_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta Growth_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + a_1 ECT_{t-1} + \varepsilon_{1t} \ldots\ldots\ldots (10)$$

$$\Delta Growth_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta Growth_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta logMHT_{t-k} + a_2 ECT_{t-1} + \varepsilon_{2t} \ldots\ldots\ldots (11)$$

$$\Delta logMHT_t = \alpha_t + \sum_{j=1}^{m-1} \phi_j \Delta logMHT_{t-j} + \sum_{l=0}^{p-1} \varphi_l \Delta CO2_{t-l} + \sum_{k=0}^{q-1} \lambda_k \Delta\, Growth_{t-k} + a_3 ECT_{t-1} + \varepsilon_{3t} \ldots\ldots (12)$$

Where, ε_{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. Φ, λ, 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: $\varphi_r = 0$ (ii) H0: $\lambda_r = 0$ (iii) H0: $\varphi_r = \lambda_r = 0$ 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: $\varphi_r = a_r = 0$ (ii) H_0: $\lambda_r = a_r = 0$ (iii) H_0: $\lambda_r = \varphi_r = a_r = 0$ where r=1, 2, 3 for all three equations.

V. Results and Analysis

We started off the analysis checking the time series properties of the variables using unit root test.

Table 2: Unit Root test (without Structural break)

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	Log MHT
China	0.949	1.87	1.548	2.597	1.87	0.122	.796	1.92	1.35	1.57	-1.95	0.67
Brazil	.694	3.77***	2.02	0.561	3.69**	2.78	.796	3.81***	1.92	0.73	-3.71**	1.33
India	.012	3.89***	1.08	0.47	4.08**	3.048	.83	3.82***	1.719	0.25	-4.02**	2.05
Russia	3.07***	2.95**	0.88	3.99**	2.489	1.419	2.97**	2.95**	0.88	7.19***	-2.26	1.42
South Africa	2.289	3.90***	1.756	2.30	3.67**	0.796	2.31	3.90***	2.165	2.38	-3.68**	0.21

*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.*

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Table 3: Unit Root Test at first difference (without Structural Break)

Series in First difference												
	ADF (Intercept)			ADF (Intercept & Trend)			PP (Intercept)			PP (Intercept& Trend)		
	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT
China	-1.505	-4.16***	-2.86*	-1.18	-4.08**	-3.03	-1.50	-4.14***	-2.86*	-1.18	-4.05**	-3.03
Brazil	-4.42***	-5.48***	-3.09**	-4.56***	-5.57***	-3.39*	-4.45***	-9.68***	-3.01**	-4.58*	-13.97***	-3.39*
India	-0.783	-5.24***	-3.19**	-4.94***	-5.08***	-3.39*	-3.97***	-15.47***	-3.17**	-4.96***	-15.65***	-3.39*
Russia	-3.23**	-6.62***	-3.22**	-3.207*	-5.07***	-3.11	-3.13**	-6.99***	-3.22**	-3.05	-18.32***	-3.03
South Africa	-4.58***	-5.19***	-3.24**	-4.51***	-5.17***	-3.96**	-4.65***	-6.87***	-3.21**	-4.61***	-9.29***	-7.41***

*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.*

The results of traditional unit root tests such as ADF and PP, reported in Table 2, indicate that growth and logMHT variables are stationary at first difference in all cases. However, both ADF and PP unit root test results suggest that CO2 emissions variable is non-stationary both in level and first difference for China. With regard to Russia and India the variable shows conflicting results. AsPerron (1989) argued that traditional unit root tests provide biased decision toward non-rejection of null hypothesis when there is structural break in variables. Moreover, macroeconomic variables undergo marked structural changes, notably in emerging economies. We checked structural break points of the variables in question for all the countries using Bai and Perron (2003) multiple break point tests. The result reported in Table 4 evidence that the variables under consideration have multiple breaks over 1992-2015. This result is also supported by Barros et al. (2011) that found that emerging economies are subject to structural change over the time. Several other studies also found structural changes in economic time series (Bansal, Dittmar, & Kiku, 2007; Filis, 2010; He, Wang, & Lai, 2010; Hendry & von Ungern-Sternberg, 1981; Plosser, 1982; Zhang & Wei, 2010). It means that with the course of time the mean and variance of these variables tend to change and move away from the given value.

Table 4: Bai-Perron Multiple breakpoint tests

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	0		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 (Econometric Journal, 2003) critical values.

As traditional unit root tests show biased results and the breakpoint tests indicate the presence of multiple breaks, we applied one structural break and two structural breaks LM unit root test proposed by Lee and Strazicich (2003), and Lee and Strazicich (2013).

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Table 5: LM Unit root test (One Structural Break)

	Trend Break Model (in level)			Crash Model (in level)			Trend Break Model (at first difference)			Crash Model (at first difference)		
Country	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT
China	-2.09	-2.40	-2.24	-0.82	-1.58	1.26	-3.01	-4.92***	-4.39***	-1.81	-4.82***	-3.84*
Brazil	-2.31	-5.22***	-1.99	-1.32	-5.10***	-1.96	-7.42***	-7.59***	-5.47***	-5.66***	-5.39***	-5.17***
India	-4.03	-4.44**	-1.87	-1.41	-4.43**	-1.99	-5.35***	-6.07***	-4.57**	-4.62***	-6.24***	-4.25***
Russia	-3.35	-5.35	-2.93	-1.16	-3.41	-1.43	-4.68***	-6.87***	-4.36**	-4.03**	-6.43***	-3.63**
South Africa	-2.73	-3.40	-3.14	-2.60	-3.33	-1.85	-5.20***	-5.31***	-4.15**	-5.57***	-4.93***	-4.39***

*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 from Lee 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.*

Table 6: LM Unit root test (Two Structural Breaks)

	Trend Break Model (in level)			Crash Model (in level)			Trend Break Model (at first difference)			Crash Model (at first difference)		
Country	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT	CO2	Growth	LogMHT
China	-2.84	-4.95	-3.48	-0.86	-1.83	-1.3723	-3.89	-7.01***	-5.36	-1.97	-4.97***	-5.07***
Brazil	-4.54	-6.32**	-2.79	-1.47	-5.46***	-2.1607	-7.76***	-8.28***	-6.07**	-6.89***	-6.04***	-5.48***
India	-4.91	-5.04	-3.22	-1.65	-4.60***	-2.1783	-8.58***	-6.82**	-10.68***	-4.91***	-6.63***	-4.67***
Russia	-4.17	-5.11	-3.66	-1.24	-4.80***	-1.60	-5.39*	-8.76***	-9.91***	-4.63***	-6.27***	-3.87**
South Africa	-4.26	-4.50	-3.91	-2.85	-3.57	-2.26	-6.25**	-5.31*	-6.02*	-5.98***	-5.07***	-4.33***

*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 from Lee 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.*

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.

Table 7: ARDL cointegration and diagnostic test results

	Model A, CO2=f(Growth, LogMHT)				Model B, Growth=f(CO2, LogMHT)				Model C, LogMHT = f(Growth, CO2)			
Country[q]	Model[g]	F[b]	LM[ζ]	HET[ƺ]	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	1.861	(1, 1, 0)	18.53***	0.487	1.39
India	(2, 0, 0)	4.44***	7.82**	14.06**	(2, 0, 0)	7.195***	1.374	0.182	(2, 3, 4)	6.14***	0.05	0.28
Russia	(2, 2, 0)	15.64***	1.541	12.39	(1, 0, 1)	15.42***	0.537	1.021	(1, 2, 2)	9.713***	0.758	7.31***
South Africa	(1, 2, 2)	2.479	0.98	4.516	(2, 1, 1)	1.506	3.944	10.12	(2, 2, 0)	0.812	2.60	4.66

*[g] As per CUSUM and CUSUMQ tests structural break occurs for model A in 2007 and 2009 for India and Russia respectively. Dummy variables are used in ARDL models for these countries for model A. ***; **; and * indicates significance level at 1%; 5%; and 10% respectively. The numbers are reported in two decimal points.*

[q] We exclude China from the analysis due to non-stationary characteristics of CO2 variable in China.

[b] 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 from Narayan (2005)

[ζ] LM is the Lagrange multiplier test for serial correlation with a χ^2 distribution with only one degree of freedom.

[ƺ] HET is test for heteroskedasticity with a χ^2 distribution with only one degree of freedom.

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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]

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 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.

Table 8: ARDL long run estimates

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

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

[Jb]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.

[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.

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Table 9: ARDL Short Run Estimates

	CO2=F(Growth, logMHT)		Growth=F(CO2, logMHT)		logMHT= F(Growth, CO2)	
Brazil			D(CO2) D(logMHT) Cointeq(-1)	-0.43 30.68*** -1.28***	D(Growth) D(CO2) Cointeq(-1)	0.02*** -0.01 -0.05*
India	D(CO2(-1)) D(Dum01) D(Growth) D(logMHT) Cointeq(-1)	-0.36 0.06** -0.002 0.101** -0.16**	D(Growth(-1)) D(CO2) D(logMHT) Cointeq(-1)	0.32 -9.82* 7.75** -1.51***	D(logMHT(-1)) D(Growth) D(Growth(-1)) D(Growth(-2)) D(CO2) D(CO2(-1)) D(CO2(-2)) D(CO2(-3)) Cointeq(-1)	-0.83* -0.01 0.01* 0.009 -0.64* -0.12 0.002 -0.74* 0.86***
Russia	D(CO2(-1)) D(Dum1) D(Growth) D(Growth(-1)) D(logMHT) Cointeq(-1)	0.398 -0.57 0.006 0.001 1.63*** -0.98***	D(CO2) D(logMHT) Cointeq(-1)	4.75* 17.78 -1.01***	D(Growth) D(Growth(-1)) D(CO2) D(CO2(-1)) Cointeq(-1)	0.01** 0.003 0.13** -0.108** -0.17**

*Note: ***; **; and * indicates significance level at 1%, 5%, and 10% respectively. Dum indicates the dummy variables. "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 9. 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.

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.

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

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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.

Table 10: Long-run causality

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 respectively. We exclude Granger causality analysis for model A for Brazil and for all models for South Africa as bounds test did not find any long run cointegration for these models.*

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.

Table 11: Short run and strong causality results

Direction of causality	Short Run Causality			Strong Causality		
	Brazil	India	Russia	Brazil	India	Russia
Growth→CO2		4.95**	0.48		8.32***	1.77
LogMHT → CO2		3.31*	0.73		7.33***	1.85
Growth, LogMHT → CO2		3.00*	0.52		5.36**	1.19
Dummy → CO2		10.70***	1.40		10.85***	2.79*
CO2→ Growth	6.10**	2.05	0.59	10.21***	9.24***	1.18
LogMHT → Growth	3.12*	0.13	3.30*	4.09**	9.13***	2.74*
CO2 LogMHT → Growth	5.45**	1.05	1.92	7.30***	6.17***	2.59*
CO2→ LogMHT	6.09**	1.13	1.05	4.06**	1.90	0.70
Growth → LogMHT	0.35	4.78***	0.75	0.43	3.94**	0.59
CO2 Growth → LogMHT	3.15**	2.82*	0.74	2.52*	2.66*	0.59

*Note: ***; **; and * indicates the rejection of null hypothesis at 1%; 5%; and 10% significance level respectively. '→' 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 42.60%, whereas this contribution is very low (2.18%) in India. The share of growth due to its own shock is maximum of 53.35% in 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.

VI. Conclusion and Policy Implication

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.

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

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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 non-stationary 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 trade-growth-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.

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.

Funding

The research was conducted by authors own finance.

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.

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Appendices

Appendix A: The Classification of trade based on technology-intensity including their SITC number as per SITC rev 3.

High Tech Products

SITC No.	Products/ Commodities	SITC No.	Products/ Commodities
525	Radio-Active Materials	764	Telecomm.Equip.PartsNes
541	Medicines,Etc.Exc.Grp542	771	Elect Power Machny.Parts
712	Steam Turbines	774	Electro-Medcl,Xray Equip
716	Rotating Electric Plant	776	Transistors,Valves,Etc.
718	Oth.Powr.Genrtng.Machnry	778	Electrical Machinery Nes
751	Office Machines	792	Aircraft,Assoctd.Equipnt
752	Automatc.DataProc.Equip	871	Optical Instruments,Nes
759	Parts,For Office Machins	874	Measure,ControlInstrmnt
761	Television Receivers Etc	881	Photograph Appar.Etc.Nes

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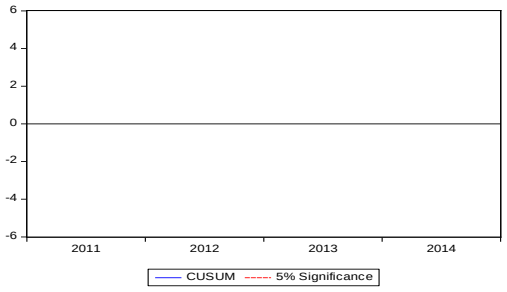
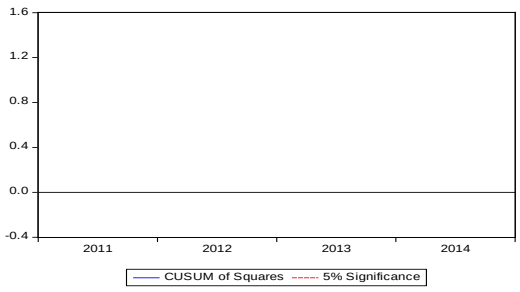
Medium Tech Products

SITC No.	Products/Commodities	SITC No.	Products/Commodities	SITC No.	Products/Commodities
671	Pig Iron,Spiegeleisn,Etc	266	Synthetic Fibres	791	Railway Vehicles.Equipnt
672	Ingots Etc.Iron Or Steel	267	Other Man-Made Fibres	882	Photo.Cinematogrph.Suppl
679	Tubes,Pipes,Etc.Iron,Stl	512	Alcohol,Phenol,Etc.Deriv	737	Metalworking MachnryNes
711	Steam Gener.Boilers,Etc.	513	Carboxylic Acids,Derivts	74	General Industl.Mach.Nes
713	IntrnlCombusPstnEngin	533	Pigments, Paints, Etc.	762	Radio-Broadcast Receiver
714	Engines,Motors Non-Elect	553	Perfumery,Cosmetics,Etc.	763	Sound Recorder, Phonogrph
721	Agric.Machines,Ex.Tractr	554	Soap,Cleaners,Polish,Etc	772	Elec.Switch.Relay.Circut
722	Tractors	562	Fertilizer,Except Grp272	773	ElectrDistribt.EqptNes
723	Civil Engineering Equipt	57	Plastics In Primary Form	775	Dom.Elec,Non-Elec.Equipt
724	Textile,Leather Machines	581	Plastic Tube,Pipe,Hose	784	Parts,Tractors,MotorVeh
725	Paper,Pulp Mill Machines	582	Plastic Plate,Sheets,Etc	785	Cycles,Motorcycles Etc.
726	Printng,BookbindngMachs	583	Monofilament Of Plastics	793	Ship,Boat,Float.Structrs
727	Food-Process.Mch.Non Dom	591	Insecticides, Etc.	812	Plumbng,Sanitry,Eqpt.Etc
728	Oth.Mach,Pts,SpclIndust	598	Misc.ChemicalProdts.Nes	872	Medical Instruments Nes
731	Metal Removal Work Tools	653	Fabrics,Man-Made Fibres	873	Meters,Counters,Nes
733	Mach-Tools,Metal-Working	781	Pass.MotorVehcls.Ex.Bus	884	Optical Goods Nes
735	Parts,Nes,For Mach-Tools	782	Goods,Spcl Transport Veh	885	Watches And Clocks
786	Trailers,Semi-Trailr,Etc	783	Road Motor Vehicles Nes	891	Arms And Ammunition

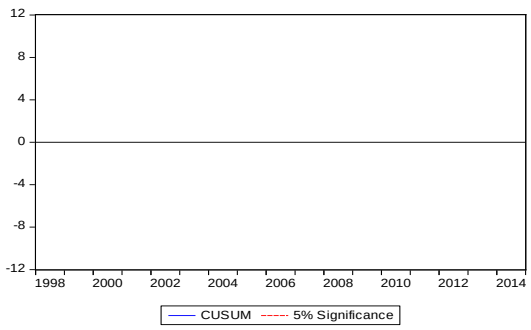
Appendix B: CUSUM and CUSUMSQ test results

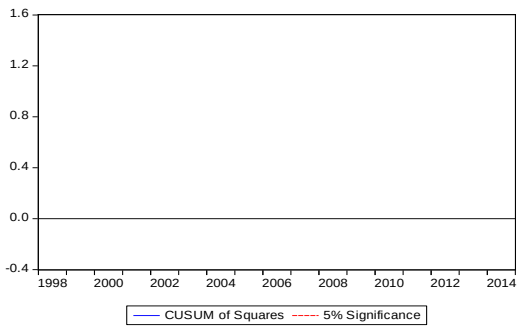
Model A





Model B





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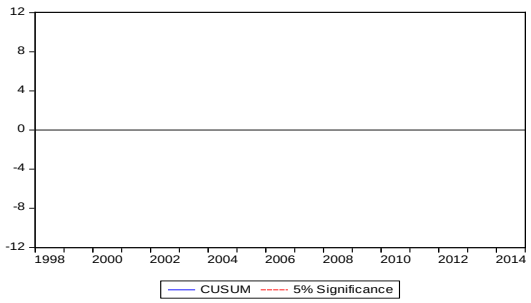
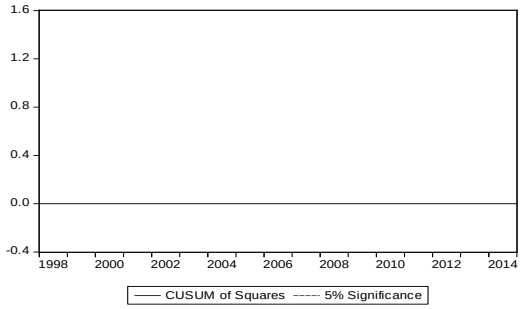
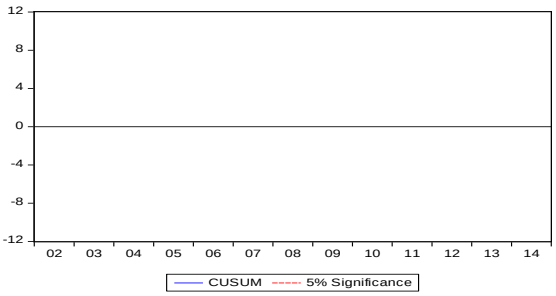
Model C

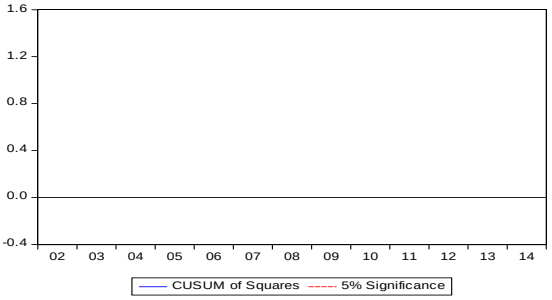




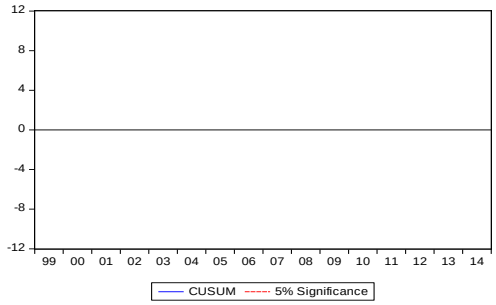
Brazil

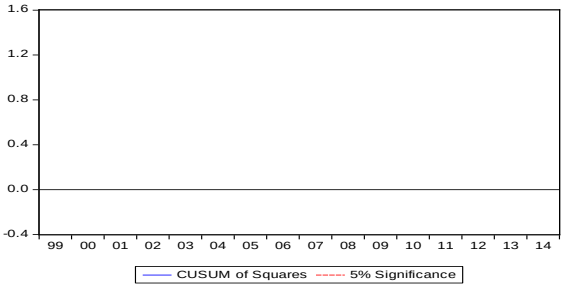
Model A



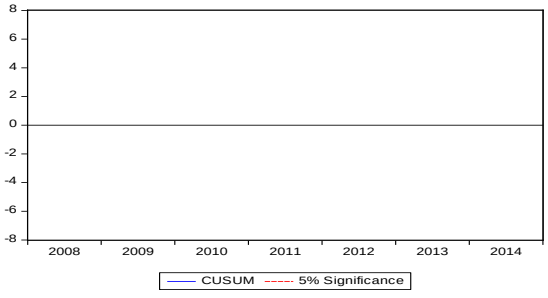


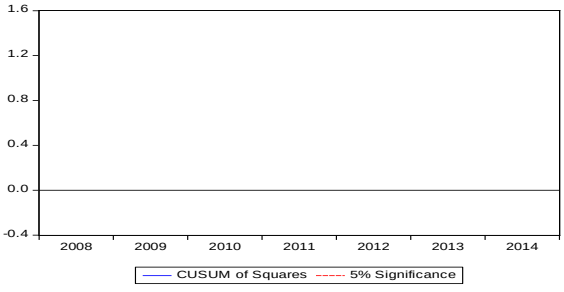
Model B





Model C





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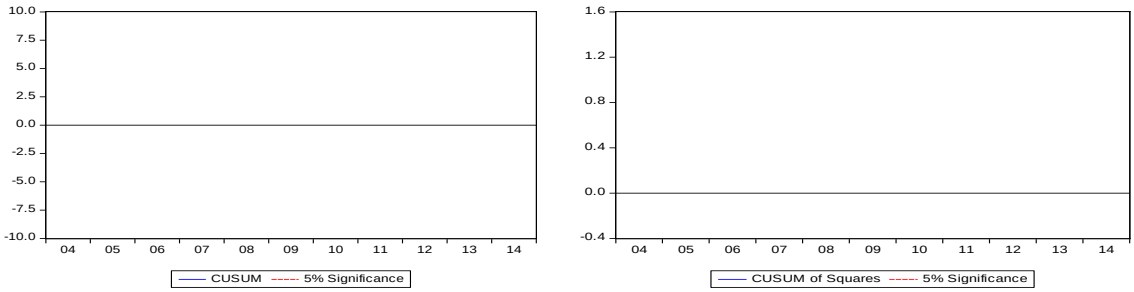
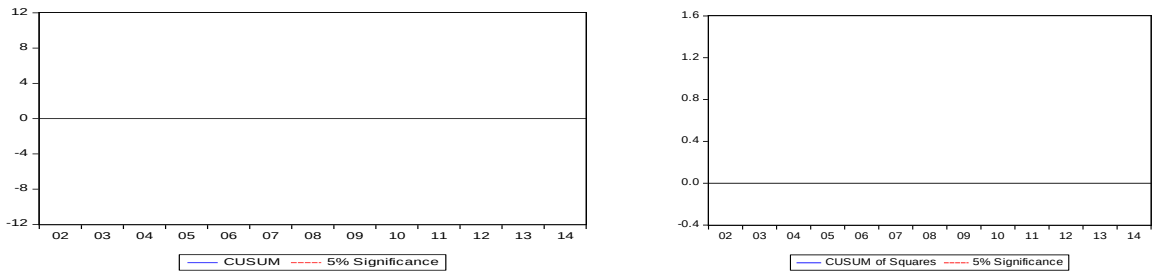
(b) India

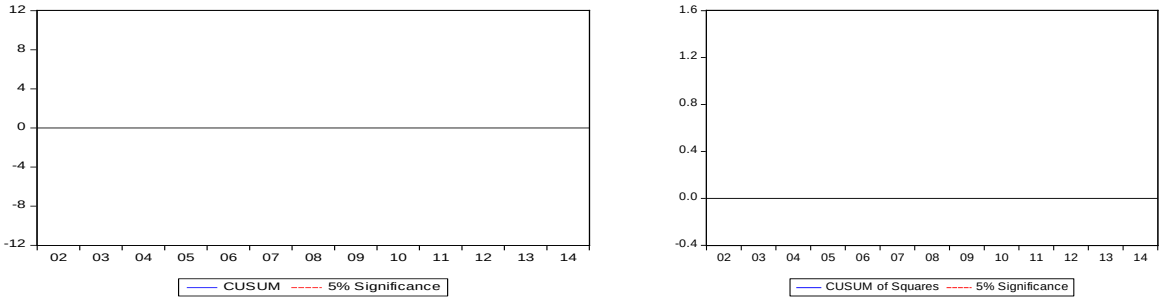
Model A



Model B



Model C

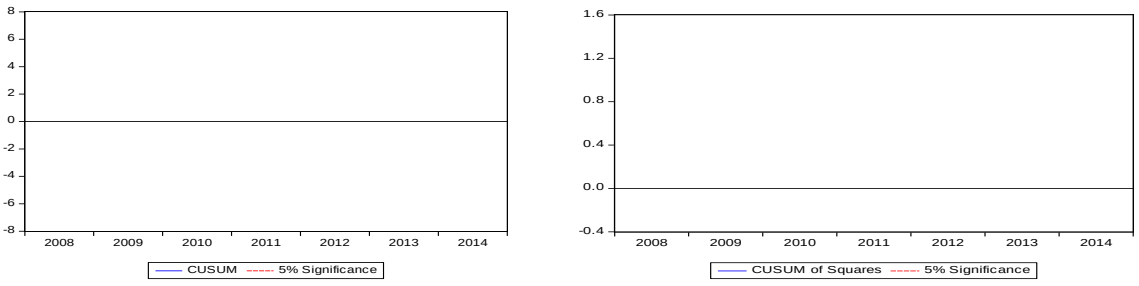


Russia

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

Appendix C: CUSUM and CUSUMQ test results including dummy variable for Model A for India and Russia

Model A: India (after dummy variable due to break)



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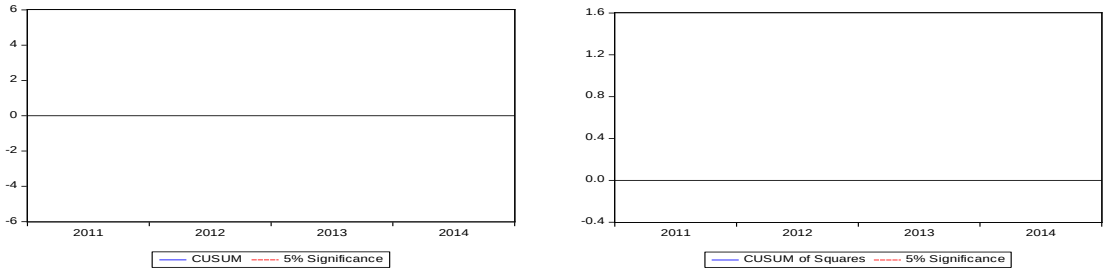
Model A: Russia (after dummy variable due to break)



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.

Appendix D: Variance decomposition analysis.

Variance Decomposition of GROWTH				
Period	S.E.	GROWTH	LOGMHT	CO2
1	1.907580	100.0000	0.000000	0.000000
2	2.343676	68.82256	1.760974	29.41647
3	2.469909	61.98371	3.400482	34.61581
4	2.498792	61.16699	3.432880	35.40013
5	2.531839	59.58832	3.354957	37.05673
6	2.560526	58.38396	3.303336	38.31270
7	2.591029	57.19610	3.227511	39.57639
8	2.624953	55.80876	3.146906	41.04433
9	2.657864	54.54284	3.078553	42.37861
10	2.689953	53.35149	3.011473	43.63704
Variance Decomposition of LOGMHT				
Period	S.E.	GROWTH	LOGMHT	CO2
1	0.057736	72.20515	27.79485	0.000000
2	0.095378	60.42507	21.78345	17.79148
3	0.127840	50.86496	15.23809	33.89695
4	0.153660	45.84432	11.85868	42.29700
5	0.174183	43.07173	10.16390	46.76437
6	0.191630	41.64146	9.194450	49.16409
7	0.207419	40.81258	8.578643	50.60878
8	0.222148	40.20640	8.136835	51.65676
9	0.236037	39.73147	7.789178	52.47935
10	0.249188	39.34405	7.508272	53.14768

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Variance Decomposition of CO2:					
Period	S.E.	CO2	GROWTH	LOGMHT	DUM01
1	0.046791	100.0000	0.000000	0.000000	0.000000
2	0.066666	92.96012	1.516106	0.741520	4.782257
3	0.089793	86.45109	8.674103	0.599234	4.275570
4	0.107374	85.20757	10.81905	0.981694	2.991685
5	0.118722	84.81478	11.02999	1.578857	2.576373
6	0.128972	84.27255	11.25439	1.847598	2.625466
7	0.139510	83.86806	11.67605	1.928059	2.527824
8	0.149383	83.65488	11.97421	2.017415	2.353490
9	0.158291	83.50076	12.13150	2.122203	2.245540
10	0.166683	83.35215	12.26010	2.198402	2.189340
Variance Decomposition of GROWTH:					
Period	S.E.	GROWTH	LOGMHT	CO2	
1	1.939181	100.0000	0.000000	0.000000	
2	2.077312	87.18448	12.81093	0.004590	
3	2.404033	73.87503	20.53946	5.585509	
4	2.493435	68.70211	21.97972	9.318171	
5	2.560482	65.46651	23.88656	10.64693	
6	2.661769	61.96373	25.81481	12.22146	
7	2.740038	58.89470	27.20521	13.90009	
8	2.810294	56.32735	28.56560	15.10705	
9	2.887268	53.92585	29.87262	16.20153	
10	2.961045	51.72596	30.99191	17.28213	
Variance Decomposition of LOGMHT					
Period	S.E.	LOGMHT	GROWTH	CO2	
1	0.049567	100.0000	0.000000	0.000000	
2	0.092549	60.62108	15.54328	23.83564	
3	0.153187	49.80877	13.31060	36.88063	
4	0.227190	46.18451	12.27785	41.53765	
5	0.309555	38.09008	14.00108	47.90884	
6	0.378502	32.10522	16.35707	51.53771	
7	0.447881	27.34625	18.12956	54.52420	
8	0.510803	23.46063	20.02738	56.51199	
9	0.561352	20.34797	21.63009	58.02195	
10	0.601147	18.06146	23.18199	58.75655	

India

Variance Decomposition of CO2:					
Period	S.E.	CO2	GROWTH	LOGMHT	DUM1
1	0.396069	100.0000	0.000000	0.000000	0.000000
2	0.495835	81.71673	0.005633	2.251958	16.02568
3	0.602419	58.46589	7.697198	1.984136	31.85278
4	0.688520	47.85013	13.91939	2.740300	35.49018
5	0.744443	44.12621	15.29203	2.843326	37.73843
6	0.802550	41.18174	14.59206	3.013656	41.21255
7	0.864412	37.69892	17.05311	3.354327	41.89364
8	0.916494	34.94042	18.74841	4.000628	42.31054
9	0.963615	32.88652	20.12780	4.379538	42.60614
10	1.010002	31.14738	21.37626	4.872904	42.60346
Variance Decomposition of GROWTH					
Period	S.E.	GROWTH	LOGMHT	CO2	
1	4.654363	100.0000	0.000000	0.000000	
2	5.199594	80.21311	11.04700	8.739890	
3	5.684654	67.45002	24.79954	7.750445	
4	6.054672	59.78734	33.38049	6.832174	

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5	6.409636	53.37288	40.06208	6.565035
6	6.741800	48.35250	44.91181	6.735694
7	7.067525	44.16129	48.95829	6.880423
8	7.400071	40.32014	52.59327	7.086584
9	7.719744	37.07857	55.70381	7.217628
10	8.025976	34.33665	58.36914	7.294210
Variance Decomposition of LOGMHT				
Period	S.E.	LOGMHT	GROWTH	CO2
1	0.117512	100.0000	0.000000	0.000000
2	0.175677	99.68094	0.318618	0.000447
3	0.210447	97.41645	0.224448	2.359106
4	0.243323	97.67790	0.188411	2.133687
5	0.269124	97.95938	0.183065	1.857551
6	0.291442	98.07463	0.157711	1.767661
7	0.314416	98.26391	0.144094	1.591993
8	0.335735	98.38654	0.133737	1.479723
9	0.355584	98.46481	0.123062	1.412133
10	0.374643	98.54473	0.115947	1.339324

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