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Title page

Structural breaks in CO_2 emissions: Are they caused by climate change protests or other factors?

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*Cover Letter

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Dear Professor B. Tansel

Editor-in-Chief, Journal of Environmental Management

Please find attached article "**Structural breaks in CO_2 emissions: Are they caused by climate change protests or other factors?**" for possible publication in your journal. The manuscript has not been previously published, is not currently submitted for review to any other journal, and will not be submitted elsewhere before a decision is made by this journal.

Sincerely yours.

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RESPONSE LETTER

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The authors are thankful to editor and anonymous referees for their constructive comments on the paper entitled " Structural breaks in CO2 emissions: Are they caused by climate change protests or other factors?" to improve the quality of our paper. We have reviewed the comments and generally agree with those comments raised. Accordingly, we have made changes in the paper in line with the referees' observations to the extent practicable.

Reviewer: 2
Authors have revised this manuscript well according to the comments and suggestions. However, citation style within main text is against the standard style of the journal. Please look into that issue before final approval. Also check for any other error before finalizing.
Many thanks to the reviewer. Citation style within the main text is corrected according to the journal citation format now.

The authors want to express our sincere gratitude for their in-depth reviews which have helped improve the quality of our paper significantly.

Professor Ilhan Ozturk, PhD

Corresponding author

Highlights

- The number and the date of structural breaks in global CO_2 emissions are presented.
- Bai and Perron (1998) structural break test for 41 countries is used alongside the Lee-Strazicich Unit Root Tests for robustness checks.
- We contribute to knowledge as regards ex-post detection of the role of climate change protests in global CO_2 emissions.
- Date of climate change protests is compared to those of these structural breaks.
- Climate change protests are fairly in agreement with break dates and differ across regions.

Structural breaks in CO_2 emissions: Are they caused by climate change protests or other factors?

Abstract

In recent times, there has been increase in climate change protest across the globe. However, whether decrease in emissions is connected with climate change protest or not is yet to be documented in the literature. Consequently, the aim of this study is to fill this gap by examining ex-post detection of how climate change protests and its interconnectedness with CO2 emissions. Using the Bai and Perron (1998) structural break test, we estimate the number of breaks as well as the date of such structural breaks in CO2 emissions series for 41 countries. Our aim is to match the date of the climate change protests to those of the structural breaks. We observe that climate change protests are fairly consistent with the dates of breaks in Europe and Asia, but not in BRICS economies or US, Canada and other countries. Therefore, this method allows us to solve a gap in the energy industry related to the modelling and correct allocation of positive shocks in CO2 emissions to climate change protests.

Keywords: Climate Change; Climate Change Protests; CO_2 Emissions; Decrease in CO_2 Emissions; Structural breaks

1. Introduction

The wave of the global fervor for industrialization has come with its attendant effect of increasing CO_2 emissions which consequently, causes natural reactions in the form of environmental pollution, global warming and climate change (Pata, 2018; Ali, 2018). These ecological problems are threatening not only the sustainability of the earth but also the survival of humanity and its development (Chu et al., 2017). Lack of water (which harms farming and forestry), air pollution (shortens life of humans and animals), increased sunlight intensity due to the depletion of the ozone layer (which consequently drains the hydrosphere) are some of the debilitating effects of greenhouse gases. This leads to the enormous volume of literature on the energy consumption-emissions-economic growth nexus with assessments of various forms of energy sources such as coal (Udi et al., 2020), and other renewable and nonrenewable energy sources (Adedoyin et al., 2020a, 2020b).

More frightening is that implementation of conservation efforts particularly in the aspects of renewable energy consumption has put the world at a crossroad in recent times (Ali et al., 2019a). This is because, this substitution comes with its attendant negative consequences on the economy particularly through job destruction, because the substitution guarantees more output for less employees (Aldieri and Vinci, 2018). Although some renewable energy projects (wind energy) have proven to be boosters of employment, the tempo is still unsustainable in the future (Aldieri et al., 2020). Ali et al. (2017) believes that any CO2 emission mitigating strategy will have to be comprehensive enough to cover areas ranging from our businesses, homes, industrial production, electricity generation, transport and etc. This top and difficult choice between the economy and the environment among other fears has continued to becloud the world policy space which consequently has led to an increase in the level of CO2 emission.

The environmental consequences of climate change make it plausible for the plethora of documented literature in the area of CO_2 emissions and its effect on the biosphere. However, data on CO_2 are found to have structural breaks (Pata, 2018). Causes attributable to these breaks are; energy crises (Ozcan and Gultekin, 2016), economic policies of the countries studied (Shahbaz et al., 2020), economic crises facing nations (Cetin et al., 2018) and perhaps policy shift in the areas of focus on renewable energy. However, there exists another realm on the possible causes of structural breaks in CO_2 emissions – climate change protests. Because it is a policy changer and policies are known to be remote cause of breaks.

Ozcan and Gultekin (2016) explained that, in the last four decades, there are important significant events that serve as key determinant that is, game changers have caused regime shifts in the trend of global emissions rates such as; the two oil crises of the 1970s, the Earth Summit of 1992 and lastly the Kyoto Protocol adopted in 1997. Commenting further, this is to say that, structural breaks can be caused by shifts in environmental legislation and policies, the political system, as well as energy price volatility.

In recent times, the lack of political will exhibited by the global leaders has triggered a lot of climate change protest globally. For example, on the 1st June, 2017, the US, who is adjudged to be responsible for about 16% of all yearly greenhouse gas emissions pulled out of the Paris Agreement deal of keeping the global average temperature below 2° C (Payne, 2018).

This is a major setback in the global campaign against global warming. Although, the US cited strategic reasons behind its action and has shown readiness to come back to the agreement table, environmental activist have labelled its act as lack of political will in tackling the menace of global warming. This lack of political will amongst other reasons prompted environmental activists to put pressure on the world leaders to act accordingly.

This has invigorated and motivated a lot of individuals particularly youths across the globe to push their respective governments and the world leaders at large to do more through several programmes of advocacy and activism (United Nations, 2013). In the words of Escobar (2015), youths across the world have been expressing their disagreement against the status quo, by seeking climate justice through movements. Notable among their approach are protests and civil disobedience.

Although climate change is a global phenomenon, however, climate change activism is majorly pronounced in the developed economies. Example of organizations championing this call are; Sierra Club, Greenpeace, Idle No More, Union of Concerned Scientists, 350.org, Global Power Shift, Friends of the Earth, Gen Zero, and Climate Youth among others. This is because, the citizens of the developed world are better informed, resourcefully and strategically advantaged - this aid in airing their message on global platforms which consequently, enable them contribute to the debate (Hayward et al., 2015).

These activists tackle climate change issues by expressing their disdain in ways that seek the reassessment of the prevailing social and economic policies (Escobar, 2015).

Majorly, they campaign against the use of fossil in order to reduce CO2 emissions and advocate for investment in green energy. According to United Nations (2013) environmental activists employ several persuasive methods in advancing their course ranging from awareness campaigns, legal redress, boycotts and even strikes.

In recent years, global activists are seen to have employed protests as the basic tool for promoting a greener world. These protests have grown bigger and have gone global with the most recent one of Sept 20th-27th, 2019. With a recorded number of 7.6 million people, who took to the streets, across 185 countries, involved over 70 trade unions, 3000 enterprises and engaged more than 8000 websites all calling for climate action, it was adjudged to be the biggest climate mobilization in history (globalclimatestrike.net).

In the opinion of Connie Hedegaard – the European Union Commissioner for Climate as quoted in United Nations (2013), this kind of massive protests have had effects by amplifying the already existing global discourse on climate change, prompting actions from global players which over the time has shaped the climate change policies. Through strikes and boycotts climate change protests have shown capabilities of causing regime shift and shaping policies as they prompt global policy makers to action as per reducing the rate of CO2 emissions globally. Policies per se are found to be a good source of structural breaks in time series data (Ozturk et al., 2010; Ozturk and Acaravci, 2013; Solarin et al., 2018; Shahbaz et al., 2020). Owing to the forgoing, it is our humble opinion that the aforementioned series of climate change protests are of significant importance in explaining the structural breaks seen in the rate of CO2 emissions globally.

To ascertain the veracity of this guess or possibility lies in answering the research question as thus: Are climate change protests the cause of the structural breaks noticed in the rate of CO_2 emissions globally or they are otherwise caused? Answering this fundamental question forms the central objective of this study. Understanding the behavior of the series of CO_2 following these trendy protests with the view of ascertaining whether structural breaks in the series are as a result of the protests or not is not only intellectually novel but hopefully will be of great contribution in the decision making process for stakeholders and policy formulation process on climate change issues.

If our hypothesis of causation of breaks by protests is found, this work will underscore the importance of these protests. Hence, the environmental activists will be taken more seriously and in turn go closer to their mandate of promoting a greener and safer earth for the future. Thus, this study is distinct from the bulk of studies documented in the related literature on the root cause of pollutant emissions in terms of scope by exploring the theme for blocs like BRICS, ASIA countries, European countries, Northern and Southern America and African for more robust empirical debate. Studies of this sort are arguably timely and pertinent for environmental scientists and governmental officials of concerned counties as policy blueprint.

2. Literature review

2.1 Structural breaks in CO_2 emissions

Although vast body of literature exist on the ecological effects of CO2 emissions, very few have worked on the issue of structural breaks in the series of the rate of emissions particularly on a global scale. Recently, there is a derive towards that direction with the view of understanding the possible cause(s) of these breaks. Basically, reasons for breaks in the series of CO_2 emissions are economic in nature ranging from economic policy shift, economic crisis to energy prices among others. While some are endogenous some are considered external. These internal shocks are largely structurally based. i.e they arise based on the nature of the economy.

It is also understood that, economic policies are tailored according to the advancement of a nation, that is why developing countries will at all times prioritize economic stability not necessarily minding the environmental consequences (Ali et al., 2019b) or downplay it, particularly during recession. This kind of policy space flexibility which gives room for policy summersault is also bound to cause regime shift in CO2 emission series. Evidence of the influence of the above-mentioned economic shocks on the structural breaks on a country's co2 series is established empirically in the literature reviewed.

For example, Cetin et al. (2018) studied the Turkish economy and found structural breaks in the series of per capita CO2 emissions in 1971 and 1993. These periods according to the authors correspond to hard time in the economic life of the Turks as they face series of economic downturn. This corroborates the finding of Cetin and Ecevit (2017) on the same economy. They examined the CO2 emission levels of Turkey as a function of its financial development by employing the Zivot-Andrews structural break test within an ARDL model and detected a regime shift in 1978 in its CO2 data series.

Furthermore, Pata (2018) studied Turkey's emission rate and determined the existence as well as positive impact of breakpoints in the series. Both ADF and Zt test statistics gotten from the Gregory-Hansen and Hatemi-J co-integration models show two breakpoints between 1997 and 1999. These breakpoints are attributable to the negative shock on the Turkish economy arising from the Asian financial crisis and the Russian banking crisis experienced during the corresponding period. The breakpoints of 1985 identified were as a result of the domestic debt crises and the burden of their five-year development plan.

Using the Zivot-Andrews and the Clemente-Montanes-Reyes unit root tests with structural breaks, Dogan and Ozturk (2017) experimented on the level of CO2 emission in the US economy within the framework of the EKC from 1980–2014. The two break dates of 1988/1980 identified are a product of banking crisis and the oil price shock of the 80s. Also, Findings suggest that emission is positively and negatively related to nonrenewable and renewable energy consumption respectively. Therefore, the EKC hypothesis does not apply for the US economy.

In the study of Kanjilal and Ghosh (2013), the possible explanations provided about the structural breaks identified in India during the period 1971 to 2008 are; trade imbalance, global energy crisis, India's economic crisis of 1991 among others. Also, growth and level of energy consumption are found to be directly related to CO2 emission in India.

Having studied the UAE from 1975-2014, Shahbaz et al. (2020) opined that structural breaks detected through the ZA test at the first quarter of 1999 is majorly caused the various economic policies implemented by the government for the improvement of economic performance.

Shahbaz et al. (2019) studied the rate of emission CO2 emissions per capita in 98 countries across the world from 1975 to 2014. Findings show the evidence of structural breaks in CO2 emissions per capita between 1982 and 2009. Here, the breaks found are a pointer to the rapid growth levels experienced in some of the sampled countries, particularly the Asian economies. The work of Ozcan and Gultekin (2016) reveal that the structural breaks seen in the series of per capita CO2 emissions of the OECD countries during the period 1960-2013 was as result of the shock from the energy crises in the 1970s.

2.2 Climate change protests

Climate change is considered by many as a call for global justice. In December 2009, the 2009 UN Climate Change Conference of Copenhagen saw a paradigm shift in environmental activism as scientists and several NGO's were prompted to key into the protest activities in Copenhagen and across the world (Wahlström et al., 2019). Recently, teenagers and youth and even children are dominating global environmental activism. For example, 17- and 15-years old Jamie Margolin and Greta Thunberg founded the protest groups Zero Hour and School Strike for the Climate respectively. This is shown in table 1 according to the Climate change protest tracker. Although youths have been in the circle of climate change debate and protests for decades, the current trend is adjudged to be louder and better coordinated (www.nature.com).

Considering table 1, there are numerous protests before the year 2000 but they are more pronounced in the new millennium. There are nine protests across Europe and Asia with even some covering the globe. Interestingly, they are largely organized by students. The recent protest of September 2019 tagged global climate strike recorded a huge success where over 7 million people took to the streets from 20th to 27th. The seed of the aforementioned protest was sawn on the climate strike of 15th February of 2019 when students walked out of classroom in protest the negligence of world leaders on the effect of climate change. Prior to this, the lone Swedish teenager, Greta Thunberg was the one considered as the pioneer of the climate change protest through School strike as she absconded from classes every Friday throughout august of 2018 and protested in front of the House of Parliament of Sweden.

The current wave of climate change activism is gaining its ground courtesy of the digital media as the new media has basically become the platform of the global advocacy for climate change (Hestres and Hopke, 2017). The trend has changed the direction of the advocacy efforts, has re-echoed the call to action on the decision-makers, which may eventually determine the policy options considered on issues of climate change.

The basic demands of these youth protest groups are simply for government to give the necessary priority environmental reforms deserve, if possible, declare a state of emergency. They enjoy widespread support from NGO's, media, their parents, teachers and some prominent scientists and scientific bodies. These supports have propelled the advocacy and has shaped policies on climate change (United Nations, 2013). These policy effects of protests can cause regime shift in the CO_2 series, hence this study.

<Insert table 1 near here>

3. Methodology and Data

3.1. Methodology

There have been scholarly debates on pollutant emission (CO_2 emissions) in time series literature with mixed conclusions from different empirical studies, which have argued whether there exist unit roots or not. Further, for unit roots, dynamics in policy in any period is likely going to have a persistent effect in succeeding periods. For desirability of outcomes such as reduction in CO_2 emission, positive impact from strategies on the elimination of CO_2 emissions or its production which may have long lasting is important. For the purpose of this study, we employed Bai and Perron (2003b, 1998) theoretical and computational testing procedures, which enables the modeler to identify unknown break periods from a specified number of observations, T and m possible breaks by ordinary least squares generating $m+1$ regimes.

Extant literature has investigated this issue in the CO_2 emission literature. Recently, Cró and Martins (2017) investigated the number and date of international tourism structural breaks for panel data using Bai and Perron (1998); tourism emergencies and incidents have been found to be largely consistent with the break dates. Therefore, to test for unit root without considering the likelihood of a structural break result to accept the hypothesis of the unit root, where in most cases it may be rejected. In situations where multiple structural breaks are accounted for, with most experiments contributing to the unit root theory being dismissed when dealing with CO2 emissions from different sources. Various techniques are employed to account for unit roots where there exist trend shifts; they however broadly produce similar results. That is, if structural breaks are not taken into account, most series are not stationary, and most series are stationary if structural breaks are accounted for. This is particularly true when testing both individual series with different techniques, as well as when evaluating the series together as a group with different tests.

Notably, it does not mean that the results of policies are necessarily temporary, even if a time series is considered to be stationary. In a break stationary time series, distorted time series may still be affected by policy in the long run growth path. Zhang et al. (2011) found similar results for renewable energy production and utilization in BRIC countries.

The procedure of Bai and Perron can be divided into three segments. Firstly, we analyze the time series unit root property. If non-stationarity established, the Bai and Perron (1998, 2003a) may be necessary to attempt to account for any structural breaks and to report the dates of such structural breaks. Next, after investigating the unit root properties of the individual segments, divided by the break dates given by the analysis by Bai and Perron (1998, 2003a), to see if the structural breaks account for the observed non-stationarity. Finally, to account for the break dates, least squares estimation will be employed using dummy variables. This enhances the directionality of the breaks provided by the technique of Bai and Perron (1998, 2003a).

3.1.1 Set up of the Bai and Perron (1998, 2003) Model

Bai and Perron (1998, 2003a) proposed methodology permit the modeler to endogenously estimate structural breaks. In other words, it is not necessary to know the timing of the breaks in advance. Following the extant studies such as Cró and Martins (2017), Rapach et al. (2005), Caporale et al. (2000) and Weideman et al. (2017), we investigate whether structural breaks in CO2 emissions are caused by climate change protests around the world.

Starting with the baseline where $t = 1, 2, 3, ..., T$ with m unknown breaks and the series are partitioned for $m+1$. Equation 1 shows that some of the coefficients contained in ρ matrix remain invariable across all partitions where others contained in a series of φ matrices represent the estimated coefficients for each partition 1 to $m+1$.The method used to calculate the coefficients in ρ and φ is that of least squares. Essentially, the parameters in the ρ and φ matrices are chosen to minimize the number of squared errors. Below is the specification of the minimization function:

$$\left(Y - X\rho - \overline{D}\varphi\right)'\left(Y - X\rho - \overline{D}\varphi\right) = \sum_{i=1}^{m+1} \sum_{t=T}\sum_{i-1+1}^{T_i} \left(y_t - x_t'\rho - d_t'\varphi_i\right)^2 \qquad (1)$$

Where the sum of squared residuals is calculated first across all time points in a given segment 1 to $m+1$. Also, $S_T(T_1, T_2, ..., T_m)$ represent the sum of squared residuals in $m - partition$ and $(T_1, T_2, ..., T_m)$ are specific to the break dates.

3.1.2 Tests for the highest number of break dates

A $\sup F$ type test was recommended by Bai and Perron (1998, 2003); to test the 0 breaks null hypothesis versus some arbitrary breaks, $m = k$. Therefore, it is possible to build an F-test in such a way that the break dates $(T_1, T_2, ..., T_k)$ are Indirectly analyzed using the fraction of the sequence in which the date occurs. Particularly, $\frac{T_i}{T} = \lambda_i$ for $i = 1, 2, ..., k$:

$$F_T(\gamma_1, \gamma_2, ..., \gamma_k; q) = \left(\frac{T - (k+1)q - p}{kq}\right) \frac{\hat{\varphi}' B' \left(B\left(\overline{D} J_x \overline{D}\right)^{-1} B'\right)^{-1} B\hat{\varphi}}{SSR_k} \quad (2)$$

The matrix R facilitates $(\hat{\varphi}B) = \varphi_1' - \varphi_2', \varphi_2' - \varphi_3', ..., \varphi_k' - \varphi_{k+1}'$. Also, J_x matrix set in such a way that $J_x = I - X(X'X)^{-1}X'$. If fact, under the alternative hypothesis, SSR_k is the number of squared residuals. The SSR_k depends on the dates of the break picked, that is, $(T_1, T_2, ..., T_k)$ of k breaks. Prior to conducting the $\sup F$ test, potential break dates can be minimized in a manner set in equation 3:

$$\Lambda_\varepsilon = \left\{(\gamma_1, \gamma_2, ..., \gamma_k); |\gamma_{i+1} - \gamma_i| \geq \mu, \gamma_1 \geq \mu, \gamma_k \leq 1 - \mu\right\} \quad (3)$$

Where a trimming parameter μ is some randomly small number. The rationale for the parameter for trimming is to show what the minimum segment length can be as a fraction of the total time series length. We then expressed the $\sup F$ statistic follows:

$$F(k; q) = \sup_{(\gamma_1, \gamma_2, ..., \gamma_k) \in \Lambda_\varepsilon} F_T(\gamma_1, \gamma_2, ..., \gamma_k; q) \quad (4)$$

The method here seeks to increase the F coefficient, which shows how much higher one version of the model is to another. The break dates are structured in such a way that random breaks can yield the largest F statistic. In other words, the excellent model with k breaks is selected and compared to the base of no break; with $H_o : m = 0$ and $H_a : m = k$ null and alternative hypotheses respectively. Bai and Perron (1998, 2003a) suggests using a double-maximum test, known as $D\max$ test with upper bound of M breaks, to estimate break dates endogenously. Extending the $\sup F$ test, the $D\max$ test is therefore presented thus:

$$D\max F_T(M, q, \omega_1, \omega_2, ..., \omega_M) = \max_{1 \leq m \leq M} \omega_m \sup_{(\gamma_1, \gamma_2, ..., \gamma_k) \in \Lambda_\varepsilon} F_T(\gamma_1, \gamma_2, ..., \gamma_k; q) \quad (5)$$

In equation 5, $(\omega_1, \omega_2, ..., \omega_M)$ signify some fixed weights related with breaks 1 to M. Given this situation, $H_o : m = 0$ is the null hypothesis while $H_o : m \textit{ is between } 1 \textit{ and } M$ represents the alternative hypothesis. The choice of these random breaks may provide additional information as to the likelihood of selecting different numbers of breaks Bai and Perron (1998). This is a theoretically open-ended question, however, as there are no precise guidelines for weight selection.

Despite this, Bai and Perron (1998, 2003a) allow for two editions of the $D\max$ test, called the $UD\max$ and $WD\max$ tests. The following weights $(\omega_1, \omega_2, ..., \omega_M)$ are generally equated to unity by the $UD\max$ test. One drawback with the $UD\max$ method is that the power of the test decreases as the number of breaks m increases for a fixed sample when the tests are weighted equally. This is because of a decrease in critical values for m large values. To solve this problem Bai and Perron (1998) also suggests a $WD\max$ test where the critical asymptotic values are used to measure the likelihood of different outcomes. The test can be expressed in two versions as follows:

$$UD\max F_T\left(M, q, \omega_1, \omega_2, ..., \omega_M\right) = \max_{1 \le m \le M} \sup_{(\gamma_1, \gamma_2, ..., \gamma_k) \in \Lambda_\varepsilon} F_T\left(\gamma_1, \gamma_2, ..., \gamma_k; q\right) \qquad (6)$$

$$WD\max F_T\left(M, q, \omega_1, \omega_2, ..., \omega_M\right) = \max_{1 \le m \le M} \frac{c(q, \omega, 1)}{c(q, \omega, m)} \sup_{(\gamma_1, \gamma_2, ..., \gamma_k) \in \Lambda_\varepsilon} F_T\left(\gamma_1, \gamma_2, ..., \gamma_k; q\right)$$

Where $c(q, \omega, m)$ represents the asymptotic critical for the test $\sup\left(\gamma_1, \gamma_2, ..., \gamma_k\right)_{\in \Lambda_\varepsilon} F_T\left(\gamma_1, \gamma_2, ..., \gamma_k; q\right)$ for an arbitrary level of significance ω and the break number, m. q represents the number of time parameters in the model varying as before. Thus as the critical values decrease for higher levels of m, the weight given to the 'maximum' F *statistic* increases.

3.1.3 Testing the number of break dates

In order to isolate the exact number of break dates, Bai and Perron (1998, 2003a) propose an F type test that will test the following hypothesis:

Should we fail to reject the null hypothesis, the inclusion of a further break does not allow for a better econometric fit between the dependent and independent variables than the set up under the null hypothesis. Should the null hypothesis be rejected, the additional break under the alternative hypothesis does a statistically significant better job of explaining the relationship between the variables. To locate the optimal number of break dates, this test is repeated l+1 times until we fail to reject the null hypothesis. The break dates under the null hypothesis are selected in such a manner that they minimize the sum of squared residuals as illustrated in the beginning of this section. The F-test statistic is expressed as follows: Bai & Perron (1998, 2003a) supports an F type test which will test the following hypothesis in order to isolate the exact number of break dates: $H_o \quad : \quad m = l$ and $H_a \quad : \quad m = l + 1$. If the null hypothesis is not rejected, the addition of a further break does not require a better econometric fit between the dependent and independent variables than that established under the null hypothesis. On the other hand, if the null hypothesis is dismissed, the additional break under the alternative hypothesis will do a statistically significant better job of explaining the relationship between the variables. To find the optimum number of break dates, this test is repeated $l+1$ times until we fail to reject the null hypothesis. The break dates under the null hypothesis are chosen in such a way that the number of squared residuals as shown before is minimized.

The F-test statistic has the following expressions:

$$F_T(l+1 \mid l) = \frac{\left\{ S_T(\hat{T}_1, \hat{T}_2, ..., \hat{T}_l) - \min_{1 \le i \le l} \inf_{\tau \in \wedge_{i\eta}} \right.}{\hat{\sigma}^2} \frac{\left. S_T(\hat{T}_1, \hat{T}_2, ... \hat{T}_{i-1}, \tau, \hat{T}_{i+1}, ... \hat{T}_l) \right\}}{\hat{\sigma}^2}$$

Where set $\wedge_{i\eta}$ is defined to:

$$\wedge_{i\eta} = \left\{ \tau; T_{i-1} + (T_i - T_{i-1})\eta \le \tau \le T_i - (T_i - T_{i-1})\eta \right\} \tag{7}$$

And $\hat{\sigma}^2$ is a consistent estimate of residual variance based on the l breaks null hypothesis. The test thus includes examining under the null hypothesis every single Segment 1 to l+1 of the model. Within each of these segments, the different break dates are then tested to see if there is a break date that can significantly reduce the sum of squared errors. In this case, η is again a trimming parameter which sets the minimum length that a segment must be if it is broken up further. As with the tests for $UD\max$ and $WD\max$, the trimming parameter is set to 25 percent. Table A.1 shows the various sources of emissions.

(Insert table A.1 near here)

3.2. Data and Variables

To study the presence of structural changes in global CO2 emissions, we collect data on several CO2 emissions for 41 countries between 1960 and 2014 from the World Bank Development Indicator database. The countries are assessed in three blocks and one association of emerging national economies i.e. BRICS, which is first presented in the discussion. The second countries to be analyzed are Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Netherlands, Norway, Poland, Hungary, Portugal, Russia, Spain, Sweden, Switzerland, New Zealand, Romania, Luxembourg and United Kingdom. For these countries, our aim is to test whether or not structural breaks are linked to any of these climate change protests in Europe presented in table 1. Other blocks of countries analyzed include China, India, Indonesia, South Korea, Malaysia, Philippines, Saudi Arabia, Thailand, Israel, Singapore, Turkey, and United Arab Emirates, all in Asia, as well as other group of major economies around the world such as Argentina, Australia, Mexico, Morocco, Nigeria, United States and Canada.

For representativeness, we analyze data on key sources of CO2 emissions such as CO2 emissions from electricity and heat production, total (% of total fuel combustion); CO2 emissions from gaseous fuel consumption (% of total); CO2 emissions from liquid fuel consumption (% of total); CO2 emissions from residential buildings and commercial and public services (% of total fuel combustion) and CO2 emissions from solid fuel consumption (% of total) that can be affected more by climate change protests. As shown in figure 1, global CO2 emissions from electricity and heat production and solid fuel consumption has been on the rise overtime. However, CO2 emissions from residential buildings have been on the decline for which we can infer on the behaviour of households towards CO2 emissions. Thus, we hypothesize a link between climate change protests and emissions from this source.

<Insert figure 1 near here>

Also, in figure 2, we find the variations in total CO2 emissions from different regions. For BRICS economies, total CO2 emissions has consistently been on the rise. However, in Europe, apart from the sharp increase in 1990, there has been downward fluctuation in the series. In figure 3, total emissions have been on the increase for the other groups of countries considered in our sample.

<Insert figure 2 and 3 near here>

4. Results and Discussions

4.1 Bai and Perron (1998, 2003a, b) structural break test

This study aimed at understanding whether protest explains the significant changes in the pattern of CO_2 emission over the last four decades. In this study, the analysis is presented in clusters including BRICS, EUROPE, ASIA and other countries. In addressing the study objective, we match the dating of protest presented in table 1 with the results we obtained from structural break analysis in tables 2. The main conclusion from our findings is that breaks in CO2 emission around the worlds are associated with factors aside protest. This however does not mean that protest is not effective but suggests that factors aside protest such as policy reforms could better explain observed changes in the pattern of CO2 emission over the last four decades.

4.1.1 BRICS

The break analysis for the BRICS is presented in the first part of table 2. The result shows that Brazil, China, India, Russia and South Africa has at least two break point over the period covered in the study. Specifically, Brazil had break point in 1984 and 1996; China had break point in 1987 and 2002; India had break point in 1990, 2001 and 2004; Russia had break point in 1996 and 2007 and lastly, South Africa had break points in 1985, 1990 and 2004. An observed pattern across these countries is that there was break point in the early 1980s, mid 1990s and early 2000s. This suggests that there exhibits some level of commonality across the BRICS countries in response of CO_2 emission.

In table 2, we present results of estimations of structural break alongside some rationale. For each country, results of the Bai and Perron (1998, 2003a, b) structural break test is presented. The test is conducted to show irregular structural breaks in CO_2 emissions. Since our aim is to test for only structural break dates that corresponds to reduction in CO_2 emissions, we present some rationale for this by identifying the protests dates in each country and other significant factor that can account for the reduction in emissions.

<Insert table 2 near here>

4.1.2 Europe

Similar to what we observed in the analysis that focused on BRICS countries, when we shifted our focus to countries in the Europe, which is reported in Table 2, we observed that over the period covered in the study, each of the selected countries in Europe had at least two break point, except for New Zealand that had only one break point. Countries like Denmark, Finland, France, Ireland, Netherlands, Norway, Poland, Hungary, Portugal, Spain, and Romania had three break points. In Germany, there was a long protest by the Anti-WAAhnsinns Festivals that commenced in 1982 and ended in 1988. This festival was observed to have effect on CO_2 emission in Germany has there was significant break point in 1984, which is the third year after commencement of the protest.

Similarly, most European countries had break point in early 1980s, especially in 1980. This could be associated with series of protest by the Friends of the Earth protest in the 1970s and the protest that held in 1980 in London and Anti-Fur Demonstration in London in 1979. We interpreted the break point occurring not only in England but other European countries in the early 1980s to be the contagion effect of the protest in the continent. In specific term, break point occurred in Denmark, Netherland, Norway, Poland, Hungary, Spain and Switzerland in 1980, 1981 in Luxembourg, 1983 in Ireland and France, 1984 in Germany and United Kingdom. In addition, we observed that most European countries experienced significant break in early 2000. Occurring few years before the series of protests that took place in mid and late 200s. This could be inferred that the protest periods do not coincide with any break point in any European countries.

4.1.3 Asian Countries

A striking evidence from these countries is that majority of the countries in Asia experienced significant break point in the early 2000s. Specifically, it occurred in China in 2002, India in 2001 and 2004, Malaysia in 2004, Saudi Arabia in 2003, Thailand in 2004, Israel in 2002, Singapore in 2003 and 2004, and Turkey in 2000. The cluster of breaks in the early 2000s suggest that Asian countries followed similar trend of change in the pattern of the emission of CO_2 in the region. The Onsan Illness Movement that took place in Korea in 1983 does not coincide with break point in Korea. However, we observed that break point occurs in the same time in other countries in the same region. These countries are Indonesia, Turkey and United Arab Emirates. We, thus, interpret our findings and suggest that the protest in a country could have effect on a nearby country CO_2 emission level.

4.1.4 North America, South America and Africa

We turn to the last cluster of countries, which comprises of countries from North America, South America and Africa. Our findings for the last cluster of countries are reported in Table 4. We observed in all the selected countries, at least two break points were observed during the period covered. The period of the occurrence of the break slightly differs from one country to another. This could imply that the change in the pattern of CO2 emission across the selected countries respond to different factors. In Canada and United States, both North America countries, significant breaks occur in 1980. This observed break could be an aftermath effect of various protest in America in the 1970s.

In sum, this study linked break point in CO2 emission data over the period covered in the study to the dating of protest in the world. Protest is a civic action by individual who aimed at making their grievances about the state of the economy or environment known and are seeking for a change. Protest against CO2 emission if effective is expected to cause a change in the pattern on CO2 emission, this change in pattern is expected to be dictate through a structural break analysis. In this study, we observed that in almost all the countries sampled in the study, at least two breaks were observed. We found that break point in Germany in 1983 coincide with the protest in the country in that same year. Since, the protest in Germany take place for a very long time, our result suggests that long protest is more likely to be observed that a short protest. Hence, we expect that the recent and more frequent protest will contribute to reduce CO2 emissions, and modelling CO2 emissions should pay more attention to breaks in the series.

4.2 Robustness Checks

4.2.1 Structural break method for Lee and Strazicich

Lee and Strazicich (2003) developed the Langrange Multiplier (LM) based structural break test to circumvent the spurious rejection problems associated with the endogenous break tests of Zivot and Andrews (1992), and Perron (1989). In line with Asemota and Agbailu (2017), we present the method of data generating process (DGP) as follows:

$$y_t = \vartheta' W_t + \varsigma_t, \quad \varsigma_t = \alpha \varsigma_{t-1} + \eta_t \qquad (1)$$

where Z_t is an exogenous vector of series and $\varepsilon_t \sim IID\ N(0, \sigma^2)$. The following two structural breaks may be considered: Model A allows two level shifts and is represented by $W_t = [1,\ t,\ D_{1t},\ D_{2t}]'$,, where $D_{kt} = 1$ for $t \geq T_{Bk} + 1, k = 1, 2,$ and 0 otherwise. T_{Bk} refers to the period of time whenever a break tends to occur. Model C comprises two level and trend changes and is defined by $W_t = [1,\ t,\ D_{1t},\ D_{2t},\ DT_{1t},\ DT_{2t}]'$, where $DT_{kt} = t - T_{Bk}$ for $t \geq T_{Bk} + 1, k = 1, 2,$ and 0 otherwise.

Remember that under the null $(\alpha=1)$ and alternative $(\alpha < 1)$ hypotheses, the DGP contains breaks consistently. For example, in model A (model C may have a similar argument), depending on the value of α, we have:

Null	$y_t = \beta_0 + d_1 B_{1t} + d_2 B_{2t} + y_{t-1} + \upsilon_{1t}$	(2)
Alternative	$y_t = \beta_1 + \chi t + d_1 D_{1t} + d_2 D_{2t} + \upsilon_{2t}$	(3)

where υ_{1t} and υ_{2t} represent stationary error terms; $B_{kt} = 1$ for $t = T_{Bk} + 1, k = 1, 2,$ and 0 otherwise; and $d = (d_1, d_2)$ and χ is the trend parameter. In model C, D_{kt} terms are added to (2) and DT_{kt} terms to (3), respectively. Remember that the null model (2) contains B_{kt} dummy variables. Perron (1989, p.1393) showed that to ensure that the asymptotic distribution of the test statistics is invariant to the size of (d) breaks given the null, it is essential to include B_{kt}. The unit root test for the two-break LM module is carried out using the regression as follows:

$$\Delta y_t = d'\Delta W_t + \varphi \tilde{B}_{t-i} + \sum_{i=1}^{n} \lambda_i \Delta \tilde{B}_{t-j} + \eta_t \qquad (4)$$

Where $\tilde{B}_t$ is a de-trended series such that $\tilde{B}_t = y_t - \tilde{\psi}_x - W_t \tilde{\vartheta},\ t = 2, ..., T$. $\tilde{\vartheta}$ is a coefficients vector in the Δy_t regression on ΔW_t and $\tilde{\psi}_x = y_1 - W_1 \tilde{\vartheta},$ where y_1 and W_1 are the first observations of y_t and W_t, respectively. Further, Δ is the difference operator, while η_t is the contemporaneous error term and distributed with zero mean and finite variance. Therefore, to correct for autocorrelation these terms $\Delta \tilde{B}_{t-j}, k = 1, ..., n$, are added. Parallel to Perron (1989) Model C's two-break analog, with two breaks in level and trend, W_t is defined by $[1,\ t,\ D_{1t},\ D_{2t},\ DT_{1t},\ DT_{2t}]$ allowing for a constant term, linear time trend, and two structural breaks in level and trend. The unit root null hypothesis is given as $\varphi = 0$, and $\tilde{\varpi} = T\tilde{\varphi}$ provides the LM test statistics, while $\tilde{\tau} =$ t-statistic for null hypothesis $\varphi = 0$.

The minimum LM unit root test uses a grid search to determine the break points (T_{Bk}) endogenously as follows:

$$LM_{\varpi} = \inf_{\gamma} \tilde{\varpi}(\tilde{\gamma}) \qquad (5)$$

$$LM_{\tau} = \inf_{\gamma} \tilde{\tau}(\gamma) \qquad (6)$$

We defined $\gamma = T_b / T$, and the sample size is represented by T. Vougas (2003) suggested that in the application of LM test, the studentized version $(\tilde{\tau})$ takes, into account, the variance of the predicted coefficients and is more effective than the coefficient $(\tilde{\varpi})$ test. It is known that the breakpoints are where the test results are minimized. A trimming region of (0.15 T, 0.85 T) is used to eliminate endpoints as expected in the endogenous break test. Critical values as tabulated in Lee and Strazicich (2003) are shown in table 3.

<Insert table 3 near here>

4.2.2 Empirical Results from Two endogenous structural breaks Lee-Strazicich Unit Root Tests

Empirical Results from two endogenous structural breaks Lee-Strazicich Unit Root Tests are presented in Table 4. The results obtained using Lee-Strazicich Unit Root Tests are qualitatively the same with the results reported in Table 3, which shows the results obtained using Bai and Perron structural break test. Since the break points are not exactly the same time with the protest periods for all countries as described in Sections 4.1.1 to 4.1.4. However, the fact that the break points are close to the period of protest in some countries is an indication that protest alone does not fully explain the break observed in the emission of CO2 is the sampled countries.

<Insert table 4 near here>

4.3. Discussion of the study findings

The trend of CO2 over the last three decades exhibit some structure break, while there are several factors identified in the literature as a possible cause of the break, the likelihood of protest in causing these structure shift in the pattern of CO2 has been neglected in the literature. This study filled this gap by linking the structural break point to the dates of protests in selected countries. The fact that activist activities has been on the rise over the last few years, justified the need for this study since time protest is a time away from productive work. However, this protest, if it contributes to reduction in CO2 emission, is a positive step in ensuring sustainable development. Ecological problems associated with CO2 emission has been argued in the literature to constitute a drag to the actualization of sustainable development.

The evidence in this study revealed that protest partly explains some of the break point inherent in the pattern of CO2 emissions over the last four decades. The implication of this study findings is that citizen of the world can contributes towards the realization of a sustainable world through their civic protest. In other words, the evidence in this study should be seen by activist that are calling for a safe world that their effort is yielding positive effect. Furthermore, the study findings suggest that government should see protest by activists as a way of calling the government to become more proactive towards protesting the ecological space and as a way of securing the environment, which is needed in ensuring that current and future generation lives in an environment that is conducive for productive economic activities as well as leisure. Instead of seeing the protests as a way of disrupting economic activities.

5. Conclusion

This study uses Bai and Perron (2003a, 2003b, 1998) multiple regime shift technique to recognize the precise number and dates of breakpoints in global CO2 emissions of 41 countries, and uses the Lee-Strazicich tests as robustness check for the results. Our empirical results propose that this strategy is demonstrated to be dependable in ex-post location of positive effects of climate change protests in reducing CO2 emissions from various. The Bai and Perron's technique have the upside of determining endogenously structural breaks and recognizing the separate dates, which permits a relationship between these dates and climate change protests dates.

Along these lines, this technique contributes in two different ways to the literature on structural break analysis in energy studies. To start with, this strategy enables us to contribute to the literature on the importance of structural break analysis in energy studies connected with the right distribution of positive shocks to CO2 emissions guaranteeing that possibilities for biased empirical result is mitigated. Second, this technique can be a significant instrument for checking the effect of a climate change protests on the trend of CO2 emissions. Since emissions arise from several sources, a climate change protest that causes a structural break ought to require a particular policy and a more prominent allotment of resources by policymakers.

This study is not without some limitations. Apart from climate change protests, CO2 emissions respond to other policies, such as green investment by the firm and government, attitudinal changes in energy consumption, among others. Thus, in cases where there are multiple protests or policy changes, the Bai and Perron method is also unable to adequately allot specific issues to CO2 emissions reduction. Also, other countries not included in the study should be assessed using the Bai and Perron method so as to compare and test the robustness of the results presented in this study.

This study can be enriched in several ways; one of such is the use of qualitative research tools. This research method will enhance the current study by providing more insights on how CO2 emission reacts to various actions aimed at reducing CO2 emission. We acknowledged the limitation of our approach in providing full explanation to break point observed in CO2 emission. However, in this paper we use econometrics tools to provide preliminary explanation to the pattern observed. Hence, future research studies should incorporate an alternative research tool, that is, qualitative research design, in understanding how industry leaders in developed and developing countries reacts to protest against CO_2 emissions as well as government policies targeted at promoting green energy. Since the adoption of green energy is not without a cost. Further research is needed in providing explanation to challenges industry leaders have to overcame before they could adopt green energy imitative. Since continued emission of CO2 is a treat to sustainable world. It therefore means that traditional production methods that contributes to CO2 emission globally should be replaced with green energy.

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Table 1. Climate change protest tracker

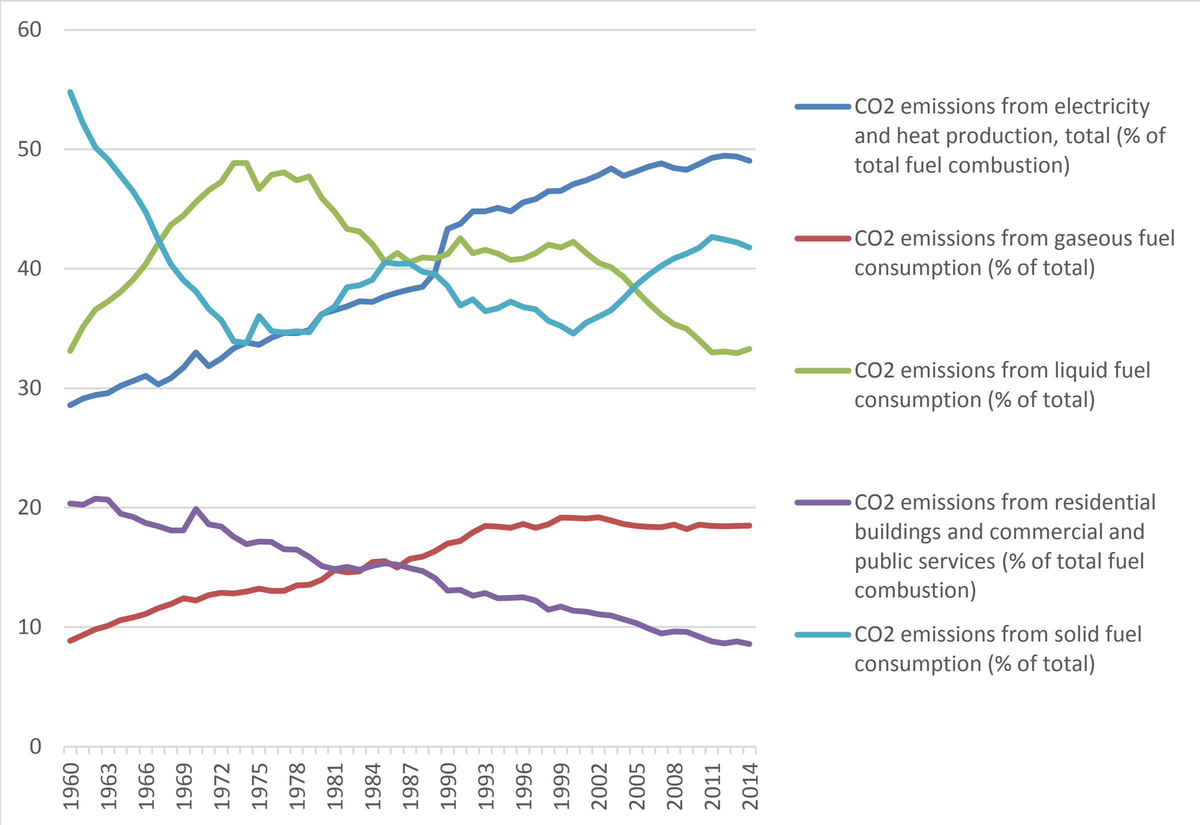
Date	Protest	Country	Organizers	Region
October 7, 2019	Die-In Protest	Berlin, Germany	Extinction Rebellion	Europe
Sept 20-27 2019	Global Climate Strike	Jakarta (Indonesia); New York (US); Berlin (Germany); Istanbul (Turkey); Quebec (Canada)	1	Multi
June 21 2019	Climate justice without borders	Germany	Fridays for Future Deutschland	Europe
May 24 2019	Second Global Climate Strike	125 countries	Climate Spring for future	global
March 22, 2019	Declaration Day	Melbourne, Sydney, Brisbane, Australia	Extinction Rebellion	Asia
March 15, 2019	Youth Climate Strike	Multi-Region (& US)	Students	Multi
On 5 March 2019,	Endorsement of strike for the climate	Germany	German researchers	Europe
February 15,2019	Strike for the climate	UK	Students	Europe
January 17-18, 2019,	Strike for the climate	Australia, Austria, Belgium, Canada, the Netherlands, Germany, Finland, Denmark, Japan, Switzerland, the United Kingdom, and the United States, Colombia, New Zealand, and Uganda	Students	Multi
December, 2018	School strike for the climate	Australia, Austria Belgium, Canada, the Netherlands, Germany, Finland, Denmark, Japan, Switzerland, the United Kingdom, and the United States	students	Multi
31 October 2018	Extinction Rebellion Protest	Parliament Square, London		Europe
August 20 2018	School strike for the climate	Sweden	Greta Thunberg	Europe
April 29, 2017	People's Climate March	Washington DC, United States	People's Climate Movement	North America
November 29 2015	Global Climate March	Europe, Asia, North America	350.org	Multi

Date	Protest	Country	Organizers	Region
April 2015	Go Fossil Free	Yale University	Fossil Fuel Divestment	North America
21 September 2014	People's Climate March	New York, US		North America
May 28, 2013	Gezi Park Protests	Istanbul, Turkey		Europe
15 December 2010	Hands Off Our Forest Protest	House of Parliament, UK		Europe
August 2010	Royal Bank of Scotland	Gogaburn, Edinburgh, UK		Europe
July 11, 2010	2010 Xinfa aluminum plant protest	Guangxi, China	Zhuang People	Asia
July 2010	Raffinerie de Normandie	Le Havre, France		Europe
December 2009	Climate Change Aotearoa	Wellington, New Zealand		Asia
August 2009	Aeroport Du Grand Ouest	Nantes, France		Europe
August 2009	Antwerp Bulk Terminal	Antwerp, Belgium		Europe
August 2009	Mainshill Woods	Scotland, UK		Europe
May 2009	Coal Caravan	Northern England		Europe
August 2008	Kingsnorth Power Station	London, England		Europe
August 2007	Kooragang Island	Newcastle Australia		Asia
August 2007	Heathrow Airport	Camp for Climate Action		Europe
31 August 2006	Camp for Climate Action	Drax, Vale of York, United Kingdom		Europe
January 2005	Stoke Hammond Protest	United Kingdom		Europe
January 2001	Green Party and Friends of the Earth protest	Grosvenor Square, London		Europe
December 1997	American Consulate Protest	Kyoto, Japan		Asia
1983	Onsan Illness Movement	Korea		Asia
1982-1988	Anti-WAAhnsinns Festivals	Germany		Europe
April 1980	Friends of the Earth protest	Britain	Friends of the Earth	Europe
February 1979	Anti-Fur Demonstration	Harrods, London	Friends of the Earth	Europe
October 1973	Friends of the Earth protest	Earls Court, London	Friends of the Earth	Europe
June 1971	Battlers for Keller's Bush	Hunters Hill, Australia		Asia
May 4 1971	May Day 1971	Washington DC, US		North America
1970	Cleveland State University Students Protests	Cuyahoga River	Cleveland State University	North America

Date	Protest	Country	Organizers	Region
			students	
April 22, 1970	Earth Day 1970	United States	Gaylord Nelson	North America
May 1968	The Night of the Barricades	France		Europe

Notes: [1]https://globalclimatestrike.net/partners

Figure 1. Global CO2 Emissions from various sources



Source: Authors compilation

Figure 2. Total CO2 Emissions (kt) from BRICS and Europe

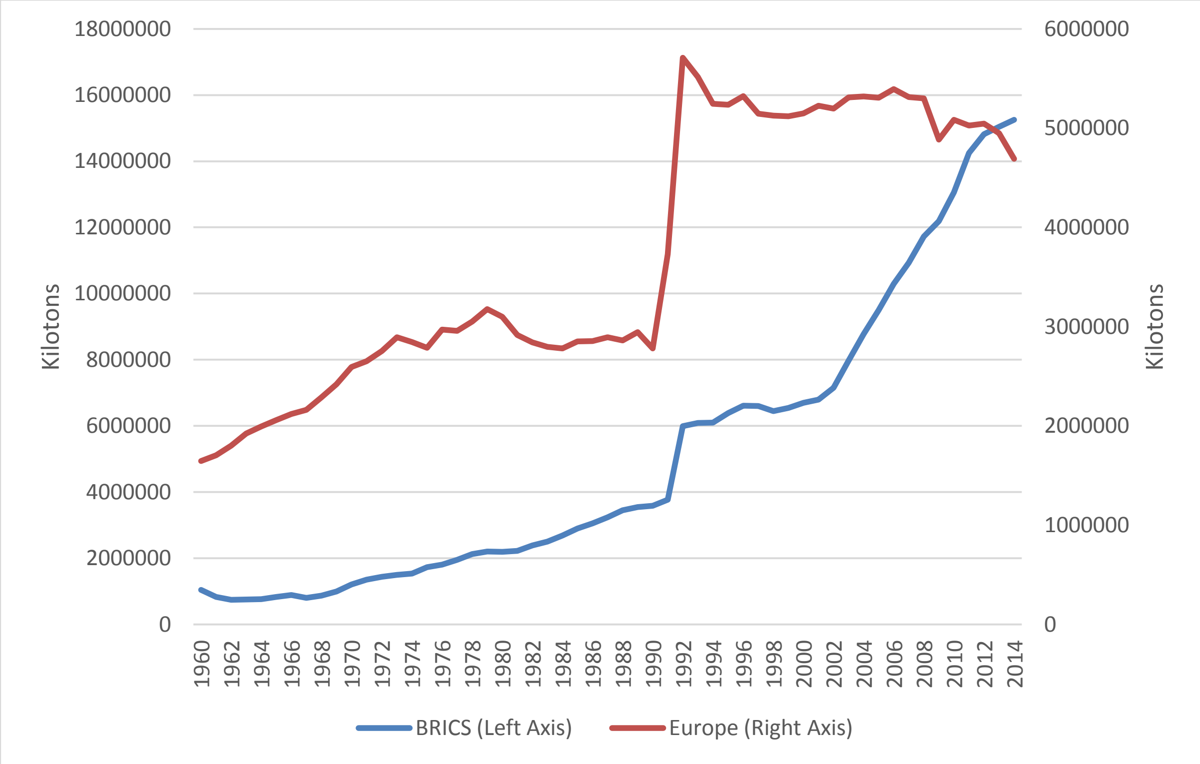


Figure 3. Total CO2 Emissions (kt) from Asia, US, Canada, and the World

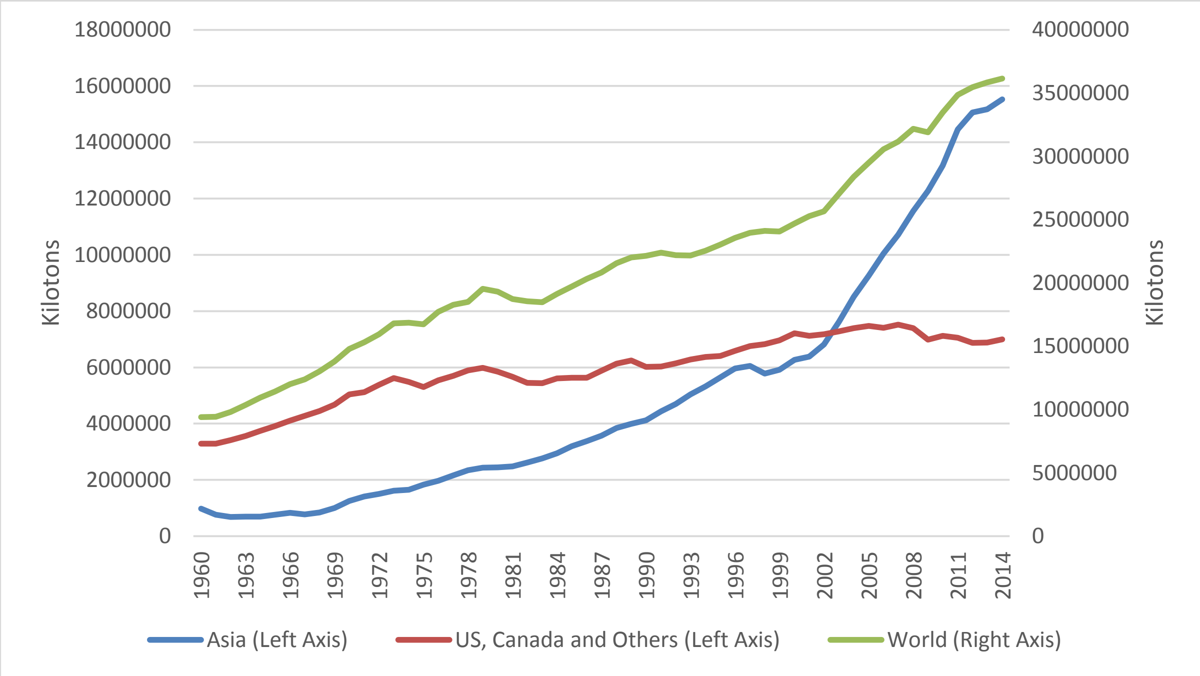


Table 2: Structural Break estimation results and its Rationale

Country	Break Test	F-statistic	Critical Values	Break Dates	Rationale
BRICS					
Brazil	0 vs. 1 * 1 vs. 2 *	109.4467 27.15922	24.18** 26.28**	1984 1996	
China	0 vs. 1 * 1 vs. 2 *	61.51148 35.59137	24.18** 26.28**	1987 2002	
India	0 vs. 1 * 1 vs. 2 *	18.99271 45.37851	24.18** 26.28**	1990 2001 2004	
Russia	0 vs. 1 * 1 vs. 2 *	12.40392 7.619200	10.55** 12.19**	1996 2007	
South Africa	0 vs. 1 * 1 vs. 2 *	24.95604 38.38753	20.75** 22.78**	1985 1990 2004	
EUROPE					
Belgium	0 vs. 1 * 1 vs. 2 *	15.33528 3.612656	24.18** 26.28**	1985 2002	
Denmark	0 vs. 1 * 1 vs. 2 *	93.75307 17.65903	20.75** 22.78**	1980 1991 1999	
Finland	0 vs. 1 * 1 vs. 2 *	5.259474 4.408818	24.18** 26.28**	1985 1986 1997	
France	0 vs. 1 * 1 vs. 2 *	24.97858 5.163720	24.18** 26.28**	1983 1985 1996	
Germany	0 vs. 1 * 1 vs. 2 *	50.32411 62.56101	10.55** 12.19**	1984 2001	Anti-WAAhnsinns Festivals
Ireland	0 vs. 1 * 1 vs. 2 *	153.2474 15.54048	20.75** 22.78**	1983 1994 2000	Green Party and Friends of the Earth protest
Italy	0 vs. 1 * 1 vs. 2 *	18.20066 34.77598	24.18** 26.28**	1987 2004	
Netherlands	0 vs. 1 * 1 vs. 2 *	21.03468 10.51313	24.18** 26.28**	1980 1993 1995	
Norway	0 vs. 1 * 1 vs. 2 *	21.58532 20.04489	24.18** 26.28**	1980 1999 2004	
Poland	0 vs. 1 * 1 vs. 2 *	37.19895 26.33464	24.18** 26.28**	1980 1990 2001	
Hungary	0 vs. 1 * 1 vs. 2 *	69.09682 167.7233	24.18** 26.28**	1980 1991 1994	
Portugal	0 vs. 1 * 1 vs. 2 *	27.09909 53.73480	20.75** 22.78**	1987 1999 2003	
Russia	0 vs. 1 * 1 vs. 2 *	12.40392 7.619200	10.55** 12.19**	1996 2007	Heathrow Airport
Spain	0 vs. 1 *	8.845061	24.18**	1980	

Country	Break Test	F-statistic	Critical Values	Break Dates	Rationale
	1 vs. 2 *	112.9801	26.28**	1995 2004	
Sweden	0 vs. 1 * 1 vs. 2 *	53.17658 13.08608	20.75** 22.78**	1987 2002	
Switzerland	0 vs. 1 * 1 vs. 2 *	51.32270 7.542221	24.18** 26.28**	1980 2004	
New Zealand	0 vs. 1 *	42.10951	24.18**	1990	
Romania	0 vs. 1 * 1 vs. 2 *	34.73583 8.500005	24.18** 26.28**	1989 1992 2004	
Luxembourg	0 vs. 1 * 1 vs. 2 *	20.95103 14.90240	24.18** 26.28**	1981 2003	
United Kingdom	0 vs. 1 * 1 vs. 2 *	196.2195 4.552673	24.18** 26.28**	1984 2004	Friends of the Earth protest Green Party and Friends of the Earth protest
ASIA					
China	0 vs. 1 * 1 vs. 2 *	61.51148 35.59137	24.18** 26.28**	1987 2002	Onsan Illness Movement
India	0 vs. 1 * 1 vs. 2 *	18.99271 45.37851	24.18** 26.28**	1990 2001 2004	
Indonesia	0 vs. 1 * 1 vs. 2 *	33.28102 21.06890	24.18** 26.28**	1983 1999	Onsan Illness Movement
Korea, dem. People's rep.	0 vs. 1 * 1 vs. 2	51.95920 0.965400	10.55** 12.19**	1996	Onsan Illness Movement
Malaysia	0 vs. 1 * 1 vs. 2 *	96.31295 4.734361	24.18** 26.28**	1986 1998 2004	
Philippines	0 vs. 1 * 1 vs. 2	33.09335 3.075438	20.75** 22.78**	1994	
Saudi Arabia	0 vs. 1 * 1 vs. 2 *	8.970550 131.6020	20.75** 22.78**	1982 2003	
Thailand	0 vs. 1 * 1 vs. 2 *	80.57873 26.67878	20.75** 22.78**	1993 2004	
Israel	0 vs. 1 * 1 vs. 2 *	139.9329 14.89641	24.18** 26.28**	1989 1991 2002	
Singapore	0 vs. 1 * 1 vs. 2 *	65.36795 75.26731	20.75** 22.78**	1992 2003 2004	
Turkey	0 vs. 1 * 1 vs. 2 *	76.16120 40.17248	20.75** 22.78**	1983 1995 2000	
United Arab Emirates	0 vs. 1 * 1 vs. 2 *	456.5209 13.06194	18.97** 20.89**	1983 1998	
US, CANADA & OTHERS					
Argentina	0 vs. 1 * 1 vs. 2 *	23.40063 9.102811	24.18** 26.28**	1990 2004	
Australia	0 vs. 1 * 1 vs. 2 *	27.33271 16.17111	24.18** 26.28**	1982 1996 1999	
Mexico	0 vs. 1 *	18.91077	24.18**	1986	

Country	Break Test	F-statistic	Critical Values	Break Dates	Rationale
	1 vs. 2 *	43.04355	26.28**	2003	
Morocco	0 vs. 1 * 1 vs. 2 *	32.32396 22.14744	24.18** 26.28**	1989 1991 2004	
Nigeria	0 vs. 1 * 1 vs. 2 *	192.7991 17.43184	24.18** 26.28**	1983 2000	
United States	0 vs. 1 * 1 vs. 2 *	69.60560 24.01756	24.18** 26.28**	1980 1981 1993	
Canada	0 vs. 1 * 1 vs. 2 *	28.14803 9.299999	24.18** 26.28**	1980 1992 1995	

* Significant at the 0.05 level. ** Bai and Perron (2003b) critical values.

Table 3. Lee and Strazicich Critical Values for Two-Structural Break Test

Break points	**Critical values**		
$\gamma = (T_{B1}/T, T_{B2}/T)$	**1%**	**5%**	**10%**
= (0.2, 0.4)	**-6.16**	**-5.59**	**-5.27**
= (0.2, 0.6)	**-6.41**	**-5.74**	**-5.32**
= (0.2, 0.8)	**-6.33**	**-5.71**	**-5.33**
= (0.4, 0.6)	**-6.45**	**-5.67**	**-5.31**
= (0.4, 0.8)	**-6.42**	**-5.65**	**-5.32**
= (0.6, 0.8)	**-6.32**	**-5.73**	**-5.32**

Source: Lee and Strazicich (2003)

Table 4. Empirical Results from Two Endogenous Structural Breaks Lee-Strazicich Unit Root Tests

S/N	Country	Coefficient S {1}	T-Stat.	Break Dates	Break points γ	Inference	Rationale
BRICS							
1	Brazil	-0.4630	-3.4275	1980 2010	0.2, 0.4	Unit root	
2	China	-0.4660	-3.4420	2002 2009	0.2, 0.4	Unit root	2010 Xinfa aluminum plant protest
3	India	-1.0344***	-6.4636	1983 2004	0.4, 0.6	Two breaks stationary	
4	Russia	-1.1093	-4.4642	1996 2010	0.2, 0.4	Unit root	
5	South Africa	-0.5024	-3.6172	1988 2007	0.2, 0.4	Unit root	
European Union							
1	Belgium	-0.8104	-5.1546	1981 1996	0.2, 0.4	Unit root	
2	Denmark	-0.9199*	-5.7631	1979 1994	0.6, 0.8	Two breaks stationary	
3	Finland	-0.8402*	-5.3152	1980 2002	0.4, 0.6	Two breaks stationary	
4	France	-0.7536	-4.8561	1981 2001	0.2, 0.4	Unit root	
5	Germany	-1.3652***	-6.0466	1994 2008	0.2, 0.4	Two breaks stationary	Anti-WAAhnsinns Festivals
6	Ireland	-0.5582	-3.8859	1995 2005	0.2, 0.4	Unit root	Green Party and Friends of the Earth protest
7	Italy	-0.6878	-4.5214	1981 2004	0.2, 0.4	Unit root	
8	Netherlands	-0.9403**	-5.8826	1981 1994	0.2, 0.6	Two breaks stationary	

S/N	Country	Coefficient S {1}	T-Stat.	Break Dates	Break points γ	Inference	Rationale
9	Norway	-1.0464***	-6.5421	1989 2006	0.4, 0.6	Two breaks stationary	
10	Poland	-0.4839	-3.5283	1975 1989	0.2, 0.4	Unit root	
11	Portugal	-0.8082	-5.1425	1987 2003	0.2, 0.4	Unit root	
12	Russia	-1.1093	-4.4642	1996 2010	0.2, 0.4	Unit root	Heathrow Airport
13	Spain	-0.3769	-3.0095	1983 2004	0.2, 0.4	Unit root	
14	Sweden	-0.8678*	-5.4674	1980 1994	0.2, 0.8	Two breaks stationary	
15	Switzerland	-1.0271***	-6.4169	1974 1999	0.4, 0.8	Two breaks stationary	
16	UK	-0.9009**	-5.6538	1980 2004	0.4, 0.8	Two breaks stationary	Friends of the Earth protest Green Party and Friends of the Earth protest Camp for Climate Action Stoke Hammond Protest
Asia							
1	China	-1.0344***	-6.4636	1983 2004	0.4, 0.6	Two breaks stationary	Onsan Illness Movement
2	India	-0.8732*	-5.4973	1990 2010	0.2, 0.8	Two breaks stationary	
3	Indonesia	-1.4849*	-5.3691	2000 2009	0.2, 0.8	Two breaks stationary	Onsan Illness Movement
4	Korea, Dem. People's Rep.	-1.0894***	-6.7425	1989 1997	0.4, 0.6	Two breaks stationary	Onsan Illness Movement
5	Malaysia	-0.3890	-3.0686	1984 2004	0.2, 0.4	Unit root	

S/N	Country	Coefficient S {1}	T-Stat.	Break Dates	Break points γ	Inference	Rationale
6	Philippines	-0.9487**	-5.9323	1990 1996	0.6, 0.8	Two breaks stationary	
7	Saudi Arabia	-1.1223***	-7.0616	1995 2000	0.6, 0.8	Two breaks stationary	
8	United Arab Emirates	-1.9087**	-5.5722	1990 1994	0.2, 0.4	Two breaks stationary	
			US, Canada & Others				
1	Argentina	-0.6238	-4.2043	1979 2004	0.2, 0.4	Unit root	
2	Australia	-0.6607	-4.3863	1989 2007	0.2, 0.4	Unit root	Kooragang Island
3	Hungary	-0.4754	-3.4875	1983 1994	0.2, 0.4	Unit root	
4	Israel	-0.7903	-5.0474	1985 1993	0.2, 0.4	Unit root	
5	Luxembourg	-0.3783	-3.0164	1980 2002	0.2, 0.4	Unit root	
6	Mexico	-0.7283	-4.7260	1979 2002	0.2, 0.4	Unit root	
7	Morocco	-0.8998**	-5.6475	1983 2002	0.4, 0.8	Two breaks stationary	
8	Nigeria	-0.6848	-4.5065	1987 2000	0.2, 0.4	Unit root	
9	New Zealand	-0.5357	-3.7771	1978 2003	0.2, 0.4	Unit root	
10	Romania	-0.4545	-3.3864	1976 1990	0.2, 0.4	Unit root	
11	Singapore	-0.9092**	-5.7014	2001 2008	0.4, 0.6	Two breaks stationary	
12	Thailand	-0.5215	-3.7091	1984	0.2, 0.4	Unit root	

S/N	Country	Coefficient S {1}	T-Stat.	Break Dates	Break points γ	Inference	Rationale
				1994			
13	Turkey	-0.7735	-4.9594	1978 2005	0.2, 0.4	Unit root	
14	Us	-0.6629	-4.3973	1981 2004	0.2, 0.4	Unit root	
15	Canada	-0.5496	-3.8441	1981 2003	0.2, 0.4	Unit root	
***, ** and * denote statistical significance at 1%, 5% and 10% respectively							

Table A.1. Sources of Emissions

Variables	Description - (Source: World Bank Development Indicator)
CO2 emissions (kt)	Carbon dioxide emissions are those stemming from the burning of fossil fuels and the manufacture of cement. They include carbon dioxide produced during consumption of solid, liquid, and gas fuels and gas flaring.
CO2 emissions from electricity and heat production, total (% of total fuel combustion)	CO2 emissions from electricity and heat production is the sum of three IEA categories of CO2 emissions: (1) Main Activity Producer Electricity and Heat which contains the sum of emissions from main activity producer electricity generation, combined heat and power generation and heat plants. Main activity producers (formerly known as public utilities) are defined as those undertakings whose primary activity is to supply the public. They may be publicly or privately owned. This corresponds to IPCC Source/Sink Category 1 A 1 a. For the CO2 emissions from fuel combustion (summary) file, emissions from own on-site use of fuel in power plants (EPOWERPLT) are also included.
	(2) Unallocated Autoproducers which contains the emissions from the generation of electricity and/or heat by autoproducers. Autoproducers are defined as undertakings that generate electricity and/or heat, wholly or partly for their own use as an activity which supports their primary activity. They may be privately or publicly owned. In the 1996 IPCC Guidelines, these emissions would normally be distributed between industry, transport and "other" sectors.
	(3) Other Energy Industries contains emissions from fuel combusted in petroleum refineries, for the manufacture of solid fuels, coal mining, oil and gas extraction and other energy-producing industries. This corresponds to the IPCC Source/Sink Categories 1 A 1 b and 1 A 1 c. According to the 1996 IPCC Guidelines, emissions from coke inputs to blast furnaces can either be counted here or in the Industrial Processes source/sink category. Within detailed sectoral calculations, certain non-energy processes can be distinguished. In the reduction of iron in a blast furnace through the combustion of coke, the primary purpose of the coke oxidation is to produce pig iron and the emissions can be considered as an industrial process. Care must be taken not to double count these emissions in both Energy and Industrial Processes. In the IEA estimations, these emissions have been included in this category.
CO2 emissions from gaseous fuel consumption (% of total)	Carbon dioxide emissions from liquid fuel consumption refer mainly to emissions from use of natural gas as an energy source.
CO2 emissions from liquid fuel consumption (% of total)	Carbon dioxide emissions from liquid fuel consumption refer mainly to emissions from use of petroleum-derived fuels as an energy source.
CO2 emissions from residential buildings and commercial and public	CO2 emissions from residential buildings and commercial and public services contain all emissions from fuel combustion in households. This corresponds to IPCC Source/Sink Category 1 A 4 b. Commercial and public

services (% of total fuel combustion)	services includes emissions from all activities of ISIC Divisions 41, 50-52, 55, 63-67, 70-75, 80, 85, 90-93 and 99.
CO_2 emissions from solid fuel consumption (% of total)	Carbon dioxide emissions from solid fuel consumption refer mainly to emissions from use of coal as an energy source.

***Declaration of Interest Statement**

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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