Environmental Science and Pollution Research (2021) 28:26449–26460
https://doi.org/10.1007/s11356-020-11912-8

RESEARCH ARTICLE

Financial development, international trade, and environmental degradation: a nonlinear threshold model based on panel smooth transition regression

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Received: 28 September 2020 / Accepted: 30 November 2020 / Published online: 23 January 2021

Abstract

Environmental degradation has severely affected the natural cycle of ecosystem. It's high time now and humans should execute strategies effectively to protect the further degradation. Initially, we need to understand the ways that might affect the environment. Thus, existing research is designed to explore the nonlinear association between financial development (FD) and carbon dioxide emissions (CO2) in the context of low-income countries by employing the yearly data of 1990–2016. The panel smooth transition regression model (PSTR) is applied, and the result confirmed that the nexus between the two variables are nonlinear. Moreover, it also shows that at a low regime, FD increases the CO2 emissions but as the economy of low-income states progress to the high regime, the association between the two variables becomes negative and significant. The study also confirms that FD can reduce CO2 emissions once it reaches a certain threshold point. Based on these findings, new insights are provided for the policymakers, and several policies are suggested to improve the environmental quality in low-income countries.

Keywords Financial development · International trade · CO2 emissions · PSTR · Low-income countries

Introduction

Human activities from overpopulation to pollution are significantly increasing the temperature of Earth and vitally changing the world around us. Nowadays, environmental degradation is considered one of the major issues of the world. The environment is uncontrollable because every organization, every sector, and every individual are responsible for the environmental degradation (Millington et al. 2019). Ecological, economic, and social disasters are due to increasing global warming. The main causes of environmental degradation are landfills, deforestation, natural causes, and most importantly emission of carbon dioxide. Further, Zhao and Yang (2020) argued that CO2 emissions are severely damaging the atmosphere and responsible for 58.8% of greenhouse gases. For business organizations, societies, governments, and even for an individual, the environment has become a hot issue. According to Collins and Zheng (2015), the most difficult question is that while maintaining economic growth, how countries can decrease the emission of carbon dioxide? Thus, humanity needs to emphasize on this question and should find out the answer as soon as possible so that global warming and natural disasters can be reduced. The growth cannot be accounted without financial development (FD) as it is inseparable (Le and Ozturk 2020). The association between FD and economic growth is crucial, as currently this association is stimulating rapidly. Additionally, many scholars argued that as financial sector

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progresses, so it fosters the carbon dioxide emission as well because it starts relying more on energy which could intensify CO2 emissions. For instance, expansion in financial services, products, institutions, and intermediaries require intensive manufacturing activities, technological up-gradation, and more industries and thus stimulate higher energy consumption which ultimately heightens CO2 emissions (Katircioğlu and Taşpinar 2017; Ehigiamusoe and Lean 2019; Lahiani 2020). The research of Jalil and Feridun (2011) also stated that industrial activities get an increase because of financial development and it results in industrial pollution. Therefore, the issues regarding the degradation of environment because of harmful economic activities have developed a vast area for further research in the context of sustainable development and environmental economics. So, in both, i.e., developed and developing states, the most challenging issue for present humanity is to protect the ecology from further destruction and boost the economy effectively. Hence, it is difficult for the people of present era to grow and upgrade technology without degrading an environment. In academic research, many prior researches focused on the association of FD and CO2 emissions (Al-Mulali et al. 2015a, b; Ozturk and Acaravci 2013; Shahbaz et al. 2013b; Dogan and Seker 2016; Tamazian and Rao 2010; Shahbaz et al. 2014a, b; Ziaei 2015, Shahbaz et al. 2017; Javid and Sharif 2016; Khoshnevis Yazdi and Ghorchi Beygi 2018; Shahbaz et al. 2019; Charfeddine and Kahia 2019; Zaidi et al. 2019; Khan et al. 2020). The studies depict that FD has a positive as well as negative association with CO2 emissions and also reveal that FD allows local companies and industries to expand business by installing new facilities, technologies, building new plants, increasing productions, and employing more labors; hence, all these activities increase the energy consumption, and it heightens the CO2 emissions, whereas some authors concluded that in stable economies, when states have sufficient resources, they start focusing on the mitigation of CO2 emissions. For instance, FD fosters research and development activities that promote economic growth, thus improving environmental performance. Additionally, FD helps countries in adopting environmentally friendly technology as well, so it helps the authorities to reduce pollution.

Environmental degradation is not only the consequence of FD, rapid growth of economy, or high consumption of energy (Hasanov et al. 2018). The environment is severely affected by some other crucial activities as well. Hence, another channel that we have incorporated in the research is termed as international trade. It has both positive and negative impacts on CO2 emissions: Positive because trade liberalization facilitates the transfer of advanced and environmental friendly technologies that help in improving environmental quality and reducing pollution and negative because increase in trade activities fosters economic growth and industrial activities which led to increase environmental pollution (Muhammad et al. 2020). In global emissions, trade-related CO2 emissions are the crucial factors; thus, understanding the role of international trade in emissions is of direct relevance to global and national emission reductions (Wang and Ang 2018). After reviewing the literature, it is observed that recently the influence of international trade on CO2 emissions has gained a great attention (Işik et al. 2017; Andersson 2018; Muhammad et al. 2020; Vale et al. 2018; Essandoh et al. 2020). However, in the past, authors studied the association of trade along with growth, energy, and environment by considering one of the following three main categories: (i) the first is as the sum of imports & exports, (ii) second is as a percent of export and imports to the total GDP, and (iii) the third is as a sum of real exports and imports over the real gross national product (GNP). So, Al-Mulali et al. (2015a, b) and Shahbaz et al. (2013a, b) accumulated trade by adding total exports and imports. Furthermore, Atici (2009), Hossain (2011), Jalil and Feridun (2011), Dogan and Turkekul (2016), Nasir and Rehman (2011), Ozturk and Al-Mulali (2015), Jayanthakumaran et al. (2012), Shahbaz et al. (2014a, b), Kasman and Duman (2015), Farhani and Ozturk (2015), Omri (2013), and Li et al. (2016) emphasized the combined trade by calculating it as the ratio of exports plus imports to GDP. Similarly, aggregated trade as the total value of exports and imports as a share of real GNP was studied by Halicioglu (2009). The authors concluded that international trade plays a major part in increasing the pollution because when countries exchange the technologies, products, and resources, it definitely boosts their energy consumption, and it results in CO2 emissions. Also, some mentioned that trade activities initially pollute the environment due to weak environmental regulations. However, at later stages of development with strong environmental policies, trade activities are more likely to diminish environmental pollution. So countries can reduce the CO2 emissions by implementing relevant strategies.

Thus, an existing research is designed to study the association between FD, international trade, and environmental degradation by employing the technique of PSTR. This technique possesses several advantages over the regression model. Hence, the following reasons have been considered while applying PSTR in the study. First of all, it permits the crucial variables such as FD and environmental degradation coefficient to alter for both time and countries. The second advantage is that the countries can move among groups and time as it enables the change in the threshold variable. The third is that in a nonlinear model, PSTR is responsible for the cross-country heterogeneity. Then, the fourth is all about the smooth change of the variable coefficients from one regime to another as it can be done easily with the assistance of a threshold variable. The last is associated with the outliers, and Gainelli et al. (2015) stated that PSTR is beneficial in minimizing the potential outliers' effect so that researcher can get the findings free from any outliers.

An existing research contributes to the literature through following three ways. The first is that it has inspected the association between FD, international trade, and environmental degradation by using the PSTR technique. Hence, previously none studied this association through PSTR, so it will fulfill the gap as well. The second is related to the countries that in our paper, we have targeted nineteen low-income countries. The reason behind selecting low-income countries is to investigate how much low-income countries' activities degrade the environment. As Essandoh et al. (2020) stated that in developed states (high-income countries), the environmental standards are very high, so mostly they transfer the production departments from their home countries to developing countries because in such states, the environmental standards are low. Also, in low-income states, the regulatory bodies are not efficient enough because they need investment to boost the economy; thus, many unethical activities that degrade the environment are being ignored by competitive authorities. Moreover, for low-income countries, the protection of environment is the secondary objective because poverty, inflation, and scarce resources do not allow them to protect the environment before resolving basic issues. Hence, the major environmental polluters are the low-income states. So it is essential to study the association between FD, international trade, and environmental degradation in this context. The third contribution is the incorporation of two indicators of FD, i.e., financial system deposits and private credit by banks.

The paper is divided into five main segments. The first includes the introduction of the paper that discusses the background of research and problem statement. Then, the second chapter consists of the literature review. Moving further, the third chapter depicts the methodology of the research along with the description of the data. Then, the fourth chapter includes the interpretation of the descriptive analysis. Additionally, the results of all tests have been discussed in this chapter. The last chapter is all about the conclusion of the research.

Literature review

Jalil and Feridun (2011) studied how the environment is affected by growth, energy, and FD in China. They considered the dataset from 1953 to 2006, and ARDL bounds testing method has been employed in the research. In study, results displayed that in China, FD is negatively associated with the pollution and degradation, whereas the other dissimilar finding of Lahiani (2020) is that FD plays an essential role in decreasing the environmental pollution. Thus, the authors concluded that in the long run, CO2 emissions occur because of trade openness, high consumption of energy, and income. Further, in China, the concept of the environmental Kuznets curve is supported by the results of the present research.

Another research was conducted by Shahbaz et al. (2013a) for inspecting the association among energy consumption, economic growth, financial development, trade openness, and CO2 emissions. The authors targeted Indonesia and considered the data from 1975Q1 to 2011Q4. Therefore, this aim was fulfilled by performing stationary analysis and employed the following two tests for a long-run association between the series in the existence of structural breaks: The first is the unit root test by Zivot-Andrews and the second is the ARDL bounds testing method. In addition, the causality between the variables and robustness of causal analysis was determined by VECM Granger causality technique and innovative accounting approach, respectively. It is confirmed from the results that cointegration is present among the variables. Hence, in the existence of structural breaks, the long-run association is present. Additionally, CO2 emissions increase due to the rapid growth in economy and more consumption of energy, but it is declined by FD and trade.

The association between FD and growth of economy in the context of middle income states is present in the literature, studied by Samargandi et al. (2015). The researchers targeted the fifty-two middle-income states by taking the data of the period 1980–2008. The techniques applied in the research were pooled mean group estimations in a dynamic heterogeneous panel setting. The findings depict that in the long run and short run, the association between finance and growth is an inverted U-shaped and insignificant, respectively. Hence, it is concluded that in middle-income states, too much finance might result in a negative impact on growth. Further, through the estimation of the threshold, the results related to the non-monotonic effect of financial development on growth are confirmed.

Shahbaz et al. (2018) analyzed the influence of FD, FDI, energy consumption, economic growth, and energy research innovations on emission of CO2. The authors used the data of the following time period, i.e., from 1955 to 2016, and on French time series data, the unit root test has been employed. The reason of applying this technique is the examination of order of integration in the presence of sharp and smooth structural breaks in the variables. Furthermore, the authors also applied the bootstrapping bounds testing technique that was proposed by McNown et al. (2018). The results depict that French carbon emission has a positive association with FDI but it is negatively associated with energy research innovations. Hence, it shows that French environmental quality can be improved through the association of financial development and carbon emissions. In the same way, the required condition for enlightening environmental quality is to promote financial stability and energy research innovations. On the contrary, there is a positive association between consumption of energy and carbon emissions, but the other point is that the

association between economic growth and CO2 emissions is an inverted U, which is a confirmation of the environmental Kuznets curve.

Adams and Klobodu (2018) focused on the twenty-six African countries, for the inspection of the association between FD and environmental degradation. Also, environmental degradation was measured by carbon dioxide emissions. The authors used the data from 1985 to 2011. Also, the following econometrics techniques were employed for the analysis of the data: (i) Chow test, (ii) cross-country regressions, and (iii) the generalized method of moments. It was observed that from 2000 to 2011, the environmental degradation faced an intensive structural change as compared to 1985–1999. Also, after employing cross-country regressions, the findings illustrated that the significant determinants of environmental degradation are economic growth and urbanization, whereas after accounting for the political regime, the financial development also seems to be a significant element of environmental degradation. At last, a robust positive connection between environmental degradation and economic growth was confirmed by applying the generalized method of moments technique.

The researchers studied the influence of energy consumption, FD, economic growth, and trade openness on the emissions of CO2. This research was conducted by Ali et al. (2019). The research was conducted in Nigeria, and researchers used the data of the following period, i.e., 1971–2010. For this purpose, an ARDL bounds testing technique was employed. The findings displayed that among the variables, there is a long-run cointegration association. Further, results of long-run estimation portray that three factors (financial sector development, growth of economy, and consumption of energy) are positively and significantly associated with carbon dioxide emissions. In contrast, trade is negatively and significantly linked with CO2 emissions. Therefore, based on the findings, the authors suggested that the government should propose policies in the favor of trade (import and export) sector through which degradation of environment can be minimized efficiently and can make the quality of environment better for living things.

Omoke et al. (2020) investigated the effect of FD on CO2 emissions. The researchers targeted the Nigerian state for this purpose and used the data from 1971 to 2014. Along with financial development, the authors also used energy consumption, income per capita, urbanization, and exchange rate. After the analysis of data, it has been concluded that the long-run relationship among the variables is confirmed after applying the linear and nonlinear autoregressive distributed lag techniques. Also, findings revealed that the proposed association is positively and significantly associated with each other. Additionally, as researchers studied the FD with respect to positive shocks and negative shocks, a significant decrease in CO2 emissions is observed at the time of positive shocks in FD. In contrast, a significant increase in the CO2 emissions is observed when there is a negative shock in FD. The findings of this study concluded that CO2 emissions strongly respond to the negative shocks more than positive shocks.

Lahiani (2020) studied the association between FD and CO2 emissions in the context of China and also incorporated the impact of energy consumption and economic growth. The author applied the following techniques, i.e., the first is the unit root test along with structural breaks and the second is a nonlinear autoregressive distributed lag model. Thus, it has been revealed from the results that in the study, the effect of asymmetric is present. Also, it is mentioned that CO2 emission decreases when financial development decreases. Hence, China can sustain the growth of an economy by fostering financial development as it helps in the decrease in CO2 emissions.

Sethi et al. (2020) conducted researched in India to find out the impact of FD, globalization, energy consumption, and economic growth on the sustainability of the environment. The authors used the data available from 1980 to 2015. The results showed that the rise in globalization and FD while trying to boost the economy of state is completely not in the favor of healthy environment. Also, the environment is degrading continuously because of the rapid globalization, growth, and high usage of energy. Therefore, it is suggested to initiate green policies across the country so that the environment can be protected from hazardous activities.

Zhao and Yang (2020) researched the association between FD and CO2 emissions in China at provincial level and further applied the principal component analysis in the study. The findings stated that CO2 emissions are reduced by 4 to 5 % at the upsurge of provisional FD. However, in some places such as Sichuan, Zhejiang, Xinjiang, Fujian, Shaanxi, and Yunnan, the increase in CO2 emissions is observed. In addition, a two-way causality between regional financial development and CO2 emissions is present, but in short term, this is not the fact. The findings displayed that CO2 emission is significantly affected by regional FD. Thus, it is recommended that there is a need to emphasize the development of China's financial sector at a regional level to prevent emissions of CO2.

Methodology

In the existing research, we have employed the PSTR technique, which was proposed by Gonzalez et al. (2005). It is stated by the authors that the PSTR technique can be viewed as a nonlinear homogeneous panel or a linear heterogeneous panel model. Hansen (2000) gave the panel threshold regression (PTR), so basically, PSTR is the generalization of the PTR model. Further, in a nonlinear model, the problem of heterogeneity can be resolved as it is a fixed-effects model

with exogenous regressors. It is a panel technique that allows for heterogeneity in the regression coefficients and in which coefficients vary over countries and time. Therefore, we can suppose the fact regarding the coefficients that through bounded function, these are in continuity of an observable variable. Also, bounded function is denoted by the transition function of this type of variable that can be changed between extreme states. Equation 1 explains the simple function of PSTR with two regimes:

$$y_{i,t} = u_i + \beta_0 x_{i,t} + \beta_1' x_{i,t} g\left(q_{i,t}, \gamma, c\right) + \varepsilon_{i,t} \quad (1)$$

The above equation includes the number of cross-sections and time dimensions. The number of cross-sections is denoted by N and time dimensions is denoted by T, respectively, then we have $i = 1,\ldots.N$, $t = 1\ldots..T$; the independent variable of the study is represented as $y_{i,\ t}$, the fixed individual effect is written as u_i , then the explanatory and control variables' vector is denoted as $x_{i,\ t}$, the transition function is stated in eq. (1) as $g(q_{i,\ t}, \gamma, c)$ and this function is dependent on threshold parameter , represented by C; threshold variable, denoted by $q_{i,\ t}$, and next is the parameter that controls the slope of transition, it is displayed by γ; and lastly the error term is symbolized as $\varepsilon_{i,\ t}$.

The present research is designed to analyze the association between FD, international trade, and degradation of environment. The sample includes the annual panel data from 1990 to 2016 of low-income countries. We have extracted the data of nineteen low-income countries. In our study, it is anticipated that there is a nonlinear association; thus, for the verification of this assumption, we have employed the nonlinear technique. The present study includes financial development and international trade as independent variables and CO_2 emission as the dependent variable, and financial development is considered the transition variable as well. We have also incorporated the population in our study. So, the aim is to analyze the impact of financial development and international trade on environmental degradation. Hence, the basic PSTR function is written below:

$$CEM_{i,t} = u_i + FDx_{i,t} + FD_1 x_{i,t} g\left(q_{i,t}, \gamma, \mathrm{c}\right) + \beta_1\, POP_{i,t} + \beta_2 TRD_{i,t} + \beta_3 GDP_{i,t} + \varepsilon_{i,t} \quad (2)$$

In the above equation, the number of cross-sections (in this study, it is nineteen low-income countries) is represented by (i), and the time frame is denoted as (T) that includes the period of 1990–2016. Further, CEM represents the CO_2 emission, FD is depicting the financial development, and the estimation is done through the proxies that include financial system deposits (FSD) and private credit by banks (PCB). Also, POP is portraying the population in millions, international trade is written as TRD, and GDP represents the economic growth. Also, in the above equation, we have the transition variable that is stated as $g(q_{i,\ t}, \gamma, \mathrm{c})$. In $g(q_{i,\ t}, \gamma, \mathrm{c})$, economic growth is denoted by $q_{i,\ t}$, and we have used it as a threshold variable. Moreover, γ and c are representing the parameter that is dependent on the slope of the transition function and threshold parameter, respectively. The other is g that shows the slop parameter and interprets the transition's smoothness from a regime to another. At last, the error term is stated as $\varepsilon_{i,\ t}$.The transition function's value is limited between zero and one.

Hence, Eq. (3) shows the logistic function that is based on the studies of Gonzalez et al. (2005) and Fouquau et al. (2008):

$$g\left(q_{i,t}, \gamma, c\right) = \frac{1}{1 + \exp\left[-\gamma\left(q_{i,t} - c\right)\right]} \quad (3)$$

In Eq. (3), the C shows the threshold parameter, and $\gamma > 0$ is the slope of the transition function which changed into an indicator function when $\gamma \to \infty$. Moreover, if $q_{it} \geq c$ the $(q_{i,\ t}, \gamma, \mathrm{c}) = 1$, and if $q_{it} < c \mathrm{and} g(q_{i,\ t}, \gamma, \mathrm{c}) = 0$. The PSTR model follows a fixed-effects panel model when $\gamma \to 0$. With an upsurge in threshold variable (FD), the FD and carbon emission coefficients change gradually and smoothly from first regime (β_0) corresponding to low levels of FD to second regime ($\beta_0 + \beta_1$) corresponding to high levels of FD. In this technique, the parameter relies on the transition variable and changes across time and countries. Thus, at the given level of q (FD), the sensitivity of FD to CO2 emissions for a particular time (t) and number of countries (i) is described by Eq. (4):

$$\varepsilon_{i,t} = \beta_0 + \beta_1 x g\left(q_{i,t}, \gamma, c\right) \quad (4)$$

In PSTR, to explore the parameters, the three steps are performed. The model linearity is confirmed in the first step. In this test, it is investigated that whether the association between the FD and CO2 emission is clarified by the linear or nonlinear models, i.e., PSTR. The null hypothesis (H_0) is the linear technique that is appropriate, and the alternate hypothesis (H_1) is PSTR with two regimes that is appropriate. ($H_0 : \gamma = 0$) i.e., null hypothesis is tested against the H_1. Gonzalez et al. (2005) stated that the correlated test is non-standardized because of the existence of unidentified nuisance in the parameter of theH_0. To address this problem, Eq. (5) is developed in which the transition function of Eq.(1) $(q_{i,\ t}, \gamma, \mathrm{c})$ is replaced by the first-order Taylor expansion around $\gamma = 0$.

$$y_{i,t} = u_i + \beta_0^* Z_{it} + \beta_1^* Z_{it} q_{it} + \beta_2^* Z_{it} q_{it}^2 + \cdots + \beta_m^* Z_{it} q_{it}^m + \varepsilon_{\mathrm{it}}^* \quad (5)$$

Equation (5) includes the remainder of the Taylor function that is represented by R_m; also, the mentioned parameters, i.e., $\beta_0^* \ldots \beta_m^*$, are multiple of γ, and $u_{it}^* = u_{it} + R_m\ \beta_1\ Z_{it}$. So, in such a situation, the equation-one testing of $H_0 : \gamma = 0$ is

similar to the testing of equation five H_0 i.e., $H_0^* = \beta_1^* = \ldots = \beta_m^*$. To check the linearity of the null hypothesis, we have used the following tests, i.e., Fischer LM test, Wald test, and likelihood test. The calculation is done by using the following equations:

$$\text{Fischer LM test} = \text{LM}_\text{f} = \frac{\frac{\text{SSR}_0 - \text{SSR}_1}{K}}{\frac{\text{SSR}_0}{\text{NT-N-K}}} \tag{6}$$

$$\text{Wald LM test} = \text{LM}_\text{W} = \frac{\text{NT}(\text{SSR}_0 - \text{SSR}_1)}{\text{SSR}_0} \tag{7}$$

$$\text{Likelihood ratio test} = -2[\log(\text{SSR}_1) - \log(\text{SSR}_0)] \tag{8}$$

In the above equations, the sum of squared residuals is explained by SSR_0 in H_0, the sum of squared residuals is explained by SSR_1 in H_1. In the Fischer LM test, $F(K, NT-N-K)$ distribution is used and K is the number of explanatory variables, N shows the number of countries, and T represents the time. In Wald and likelihood test $x^2(K)$ distribution is followed.

The association between the variables can be estimated by the PSTR with at least two regimes, in the situation when the null hypothesis of linear relationship faces rejection because this rejection confirms that the relationship is nonlinear. Then after this, the null hypothesis of no remaining nonlinearity is examined. The purpose of this test is to check whether the nonlinear association between the variables can be taken by the PSTR with two regimes or not. The appropriateness of both hypotheses, i.e., H_o and H_1, is as follows: PSTR with two extreme regimes and PSTR with at least three regimes, respectively. The model measured for this is stated below:

$$y_{i,t} = u_i + \beta_0 Z_{it} + \beta_1 Z_{it} g_1\left(q_{it}; \gamma_1, c_1\right) + \beta_2 Z_{it} g_2\left(q_{it}; \gamma_2, c_2\right) + \varepsilon_{it} \tag{9}$$

In Eq. (9), $H_0 : \gamma_2 = 0$ is used for the calculation of the null hypothesis; hence, it arises a similar problem of identification. So, by following the prior solution, this can be overcome by employing the Taylor expansion of $g_2\left(q_{it}; \gamma_2, c_2\right)$ around $\gamma_2 = 0$. However, it results in the equation that is written below:

$$y_{i,t} = u_i + \beta_0^* Z_{it} + \beta_1^* Z_{it} g_1\left(q_{it}; \gamma_1, c_1\right) + \beta_{21}^* Z_{it} q_{it} + \cdots + \beta_{2m}^* Z_{it} q_{it}^m + \varepsilon_{\text{it}}^* \tag{10}$$

The above equation includes the restated forms of the hypothesis. So, $H_0^* : \beta_{21}^* = \ldots = \beta_{2m}^* = 0$ is the restated form of PSTR model null hypothesis ($H_0 : \gamma_2 = 0$). The tests are performed through Wald, Fischer, and likelihood tests. Also, it is concluded that PSTR with one transition and two regimes is appropriate to inspect the association between the variable if the null hypothesis is accepted. On the other hand, we need to repeat the procedure unless the null hypothesis of no remaining nonlinearity is accepted; this needs to be done at the time of rejection of the null hypothesis. Lastly, after selecting the regimes, it is necessary to use a nonlinear least square method for the estimation of the parameters of the model.

Data

We have designed this paper to study the association between FD, TRD, and CO2 emissions; thus, we have used the annual data from 1990 to 2016 and have emphasized on the nineteen low-income states. The reason for considering the following years is the availability of data. Further, Table 1 depicts the information of selected countries. The variables are measured as follows: (i) environmental degradation is estimated by CO2 emissions (metric tons per capita) and CO2 emissions (kt); (ii) the two proxies have been used for estimating the financial development, i.e., financial system deposits as a percentage of GDP and private credit by banks as a percentage of GDP which is in accordance with the study of Zafar et al. (2019); (iii) economic growth has been measured by GDP per capita (constant 2010 US$); (iv) international trade is estimated through the percentage of GDP; and lastly, (v) population is measured by the total population in millions. The data is extracted from the World Bank database. Moreover, to interpret the independent variables' coefficient estimates regarding the dependent variable, the data has been changed into a natural logarithm.

Table 1 List of countries (alphabetical order)

S. No.	Name	S. No	Name
1	Burkina Faso	11	Malawi
2	Burundi	12	Mali
3	Central African Republic	13	Mozambique
4	Chad	14	Niger
5	Congo, Rep.	15	Rwanda
6	Gambia, The	16	Sierra Leone
7	Guinea	17	Sudan
8	Guinea-Bissau	18	Togo
9	Haiti	19	Uganda
10	Madagascar		

Data analysis

Descriptive statistics

First of all, the descriptive statistics have been employed in the present research to have a clear understanding of the basic features of data. Table 2 shows the results of descriptive statistics. The average value of CO_2 emission is 0.123 with minimum and maximum values of 0.016 and 0.445, respectively. The proxies of financial development reveal that the mean value of financial system deposits and private credits by the bank are 13.631 and 9.681, respectively. Furthermore, 83.121 is the maximum value of financial system deposits, and 0.781 is the minimum value. Similarly, the maximum value of private credits by the bank is 38.025, and the minimum value is 0.874. Moving further, the values of international trades reveal that the average, maximum, and minimum values are 50.890, 131.485, and 11.087, respectively. Similarly, in the case of economic growth and population, we have observed that economic growth has a mean value of 560.574 along with the following maximum (1866.222) and minimum values (200.298). Lastly, the population showed an average value of 13.663, with a maximum value of 78.789 and a minimum value of 0.956.

Cross-sectional dependence

After analyzing the descriptive data of our research, we applied a cross-sectional dependence test (CD) that was initiated by Pesaran (2004). The results are represented in Table 3. It is argued that while conducting the panel research, we should first inspect the presence of cross-sectional dependence, stated by Dogan and Seker (2016). Hence, the purpose of applying the CD test is to investigate whether the data possess cross-sectional independence or not. The results of the CD test are mentioned in Table 3; it is revealed that all variables have the associated p values less than 0.1; thus, it indicates the acceptance of the alternative hypothesis and rejection of the null. Therefore, it is confirmed that our data possess cross-sectional dependence. The results are similar with the prior researches as well (Raza et al. 2020; Jiang et al. 2020).

Table 3 Results of Pesaran (2004) cross-sectional dependence test

Variables	Test statistics	p Value
CEM	48.257	0.000
POP	66.215	0.000
GDP	53.258	0.000
TRD	12.589	0.000
FSD	33.557	0.000
PCB	40.891	0.000

All variables are significant at 1% level

Source: authors' estimation

Unit root test

The unit root is applied after the CD test. This test is applied to explain the stationary properties of the variables. Table 4 explains the results and depicts that at level, all the variables are non-stationary but become stationary at *I(I)*.

Panel smooth transition regression technique

We have adopted the following two steps in the PSTR analysis. The first is the linearity test and the second is the estimation of the number of regimes. Firstly, it is essential to perform the linear test so that it can be identified that either the nexus between the proposed variables is inspected by the linear or nonlinear models. So Table 5 explains the PSTR result and shows the acceptance of the alternative hypothesis and the

Table 2 Descriptive statistics (before taking logarithm)

Variable	CEM	POP	GDP	TRD	FSD	PCB
Mean	0.123	13.663	560.574	50.890	13.631	9.681
Median	0.093	9.838	514.190	47.963	12.059	8.610
Maximum	0.445	78.789	1866.222	131.485	83.121	38.025
Minimum	0.016	0.956	200.298	11.087	0.781	0.874
Std. Dev.	0.079	12.745	240.151	18.913	9.603	6.574
Skewness	1.176	2.257	1.956	0.918	2.341	1.240
Kurtosis	4.055	9.239	9.986	4.170	12.640	5.094
Jarque-Bera	142.105	1267.588	1370.266	101.286	2455.243	225.190
Probability	0.000	0.000	0.000	0.000	0.000	0.000
Observations	513	513	513	513	513	513

Source: authors' estimation

Table 4 Results of stationary analyses

Variables	Im, Pesaran, and Shin			
	I(0)		I(1)	
	C	C&T	C	C&T
CEM	3.258	−0.025	−4.119***	−4.258***
POP	0.226	−0.098	−7.358***	−6.875***
GDP	0.369	0.023	−6.344***	−6.357***
TRD	1.220	0.338	−4.227***	−5.257***
FSD	0.875	−0.583	−5.025***	−4.998***
PCB	1.996	−0.697	−6.325***	−4.278***

***, **, and * indicate respectively the significance levels at 1%, 5%, and 10%

Source: authors' estimation

rejection of the null hypothesis, thus concluding that the FDI employs a nonlinear association between the FD and CO2 emissions. Also, this association should be explored by the PSTR model.

When the nonlinearity is confirmed, then in the second step, the number of regimes is estimated by employing the no remaining nonlinearity test. Table 6 depicts the results, and based on these results, we have concluded that our results accept the following statement that says PSTR model with one transition or two regimes (H_o) and reject the statement that says PSTR model with at least two transitions and three regimes (H_1). Thus, in this situation, the null is accepted, while the alternative hypothesis is rejected. To conclude the results, we state that it is adequate to study the nonlinear association between the FD and CO2 emissions through the PSTR technique. The studies of Mosikari and Eita (2020), Raza et al. (2020), and Jiang et al. (2020) also depict the same results.

At last, Tables 7 and 8 represent the result of the PSTR technique. Concerning the PSTR technique, it is stated by Fouquau et al. (2008) that estimated values cannot be interpreted directly; thus, estimated values possess no importance in the PSTR model. However, the estimated sign holds great importance (Ulucak et al. 2020).

In the present research, two indicators of FD have been used, so based on the two indicators, we have performed the tests of two different models (Tables 7 and 8). Both models displayed that in a low FD regime, FD is positively and significantly associated with CO2 emissions. However, as a country moves to the high FD regime, then we observe that FD is negatively and significantly associated with CO2 emissions. Therefore, it is confirmed that both indicators of FD affect the CO2 emissions differently.

The influence of financial system deposit (FSD) on CO2 emissions is reported in Table 7. We can see that in low regime, FSD positively and significantly affects the emission of CO2. Then, the same association becomes negative and significant in the high regime of FD. The point above which FSD reduces the CO2 emissions is the minimum threshold value, i.e., 0.358. Hence, based on the findings, we can state the following that CO2 emission declines by FSD when FD reaches above the threshold point. This result depicts that initially, countries aim to emphasize the industrial and service sectors as these sectors are considered to be an important revenue generator. Hence, if low-income countries spend on these sectors, then they are more likely to get high taxes and revenue. However, during this situation, countries do not focus on the environment and ignore the harmful activities because the primary concern is to boost the economy. Also, Eltayeb et al. (2010) stated that various business activities such as manufacturing, sourcing, marketing activities, and logistics are the major sources of degradation of environment. Hence, initially, these activities affect the environment, but slowly and gradually, as the countries move to the high regime, carbon dioxide emission decreases, and the reason is that now, countries start paying attention to the protection of the environment. When it reaches the maturity level, the countries initiate allocating the budget on ways through which the environment can be protected. For instance, the government can make it mandatory for industries to implant technologies that are energy efficient and environmentally friendly. Hence, it will help the low-income industries to reduce the CO2

Table 5 Linearity test

Threshold variable	Lagrange multiplies—Wald test (LMW)		Lagrange multiplies—Fisher tests (LMF)	
	Statistics	*p* Value	Statistics	*p* Value
FSD	150.459	0.000	19.557	0.000
PCB	86.224	0.000	27.637	0.000

H_1 PSTR model with at least two regimes

Ho linear panel model

Source: authors' estimation

Table 6 Test of no remaining nonlinearity

Threshold variable	Lagrange multiplies—Wald test (LMW)		Lagrange multiplies—Fisher tests (LMF)	
	Statistics	*p* Value	Statistics	*p* Value
FSD	7.156	0.586	1.354	0.235
PCB	8.016	0.331	0.987	0.468

H_1 PSTR model with at least three regimes

Ho PSTR model with two regimes

Source: authors' estimation

emissions effectively. Similar results are revealed by prior studies such as Agbanike et al. (2019) for Nigeria and Mahalik et al. (2017) for Saudi Arabia.

The association between private credits by banks (PCB) and CO2 emission is presented in Table 8; the results depict that in a low FD regime, PCB is positively and significantly associated with CO2 emissions; hence, it means that it has a direct association; as PCB increases, the emission of CO2 also increases. The results depict that initially, private credits by banks are used for the betterment of the economy as low-income countries primarily aim to fix their basic issues such as GDP, tax collection, and revenue. After sometimes, when low-income countries move towards the high regime of FD, then at this point, the association becomes negative and significant. The minimum threshold point of FD above which PCB reduces the CO2 emission is 0.428. It means that when PCB increases, so it decreases the CO2 emissions. Thus, we conclude that in high regime, low-income countries can prevent the environmental degradation as now they are in the state that they can invest in sustainable development as well. Moreover, the government creates the way for industries so that they can contribute in the protection of environment, such as offer loans at low interest rates, allocate minimum taxes, and purchase of heavy machineries that play an efficient role in the reduction of CO2 emissions. The result is similar to the findings of Eren et al. (2019) and Hassine and Harrathi (2017).

Conclusion

The deterioration of environment through depletion of resources such as water, air, and soil and also the extinction of wildlife and destruction of ecosystem through hazardous gasses, deforestation, and harmful activities all come under the concept of environmental degradation. Additionally, when humans disturb the natural ecosystems, it results in disastrous changes for long term. Hence, it is necessary to study all the factors from several perspectives. We conduct this research to study the impact of FD and international trade on environmental degradation, i.e., CO2 emission. Also, to understand the mechanism in low-income countries that how they are degrading the environment. Thus, the findings of our research support the research objectives as well. The results reveal that initially, low-income countries do not take measures for the protection, but as soon as they start progressing in this domain, it ultimately decreases the emission of CO2.

Environmental change has become a serious issue in the present era. Several factors have been identified among which the financial development is recognized as the main cause of CO2 emissions. In the past, researchers studied the association between the variables by employing the linear association, but very limited studies have examined the nonlinear association. Therefore, this study gives new insights into the effect of FD and CO2 emissions along with international trade in low-income countries by using the yearly data that consist of the

Table 7 PSTR model estimations with financial system deposits

Variables	β_0	*t*-stats	β_1	*t*-stats
POP	0.482***	2.897	0.897***	3.247
GDP	0.538***	3.521	−1.245***	4.215
TRD	0.114	1.085	0.525*	1.874
FSD	0.358**	2.057	−0.789***	3.142
Threshold (c)	1.208***	6.559		
Slope parameter (γ)	42.587***	4.257		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, and * indicate respectively the significance levels at 1%, 5%, and 10%

Table 8 PSTR model estimations with private credit by banks

Variables	β_0	*t*-stats	β_1	*t*-stats
POP	0.561***	3.327	0.897**	2.485
GDP	0.625***	4.214	−1.125***	3.854
TRD	0.187	0.518	0.341*	1.705
PCB	0.428***	2.826	−0.861***	3.207
Threshold (c)	1.067***	5.198		
Slope parameter (γ)	60.258***	9.247		

β_0 and β_1 stand for regime 1 and regime 2, respectively

***, **, and * indicate respectively the significance levels at 1%, 5%, and 10%

years 1990–2016. The results have been analyzed by using the PSTR technique. The result confirmed that the association between the variables is nonlinear. Secondly, the association between the FD and CO2 emissions is positive and significant in low regimes, but as the economies progress to a high regime, the relationship between the two variables becomes negative and significant. Hence, it shows that initially, the target of countries is to focus on their industries and service sectors as they are the crucial source of income for low-income countries. Hence, in this situation, low-income countries do not pay attention to the environment on how much the environment is deteriorating by harmful activities. Low-income countries are not developed and presently fighting to sustain in this fast-paced world. Thus, no investment is done on the protection of the environment, and their operations increase CO2 emissions. However, the results show that after sometimes, CO2 emission decreases because now, countries start investing a little amount on the ecological departments.

The results represent that the association between FD and the environment is not robust as CO2 emissions can be minimized only after when the FD reaches a certain threshold point. Thus, this means that low-income countries should strengthen FD usage in improving environmental quality. The government should start cooperating with the rating organizations to choose efficient investments and also impose strict obligations on people of other countries. During the investment process, the financiers should be asked to share information related to CO2 emissions. Also, there is a need to have a contract that includes the terms and conditions regarding the prevention of emission of CO2. Due to the threshold effect of FD, low-income countries should frame high standards related to FD. It is suggested that the government should give entry to those multinational companies that use and foster clean and green technologies and should also encourage foreign investors to use their capital in efficient and high-tech production. Moreover, to improve the existing industries' production process, there is a need to upgrade the technology. Thus, the government of low-income states should invest in green technology and focus on converting existing industries into low carbon emissions industries.

The result shows that international trade increases CO2 emissions. To overcome this effect, we recommend the government to aggressively finance and allocate budget for this sector as well, such use of harmful materials should be banned in low-income countries. Also, the government should make it compulsory for all states to follow international agreements regarding the environment. There is a need to impose strict rules while trading. Additionally, low-income countries should collaborate with growing states that are efficient in the prevention of environmental degradation so that carbon emissions can be under controlled in these countries as well. This will allow them to focus on sustainability and efficient energy use in production, transportation, importing, exporting, and other economic activities.

The result also shows that the population increases CO2 emissions. It is suggested that the government should implement regulatory policies that increase public awareness towards the usage of renewable energy sources and motivate them to implement its usage in daily life by using solar water heaters, solar planes, etc. All these outcomes will minimize nonrenewable energy consumption and diminishes the CO2 emissions.

The last factor is economic growth, and it depicts that in low regime, GDP increases the carbon dioxide emission, but as it starts moving towards high regime, then GDP starts diminishing the CO2 emission. Hence, it is recommended that low-income countries should emphasize the ways through which the economy can be fostered. So, for this purpose, the revised and appropriate policies are needed as it will help in the protection of the environment as well.

Limitations of the research and future recommendations

In our research, there are some constraints that can be addressed in the upcoming period. The first limitation is related to the data availability as a result of which some factors of CO2 emissions such as ecological footprint and carbon footprints are not considered in the given model. Secondly, the threshold variable used in this study is FD; there are other variables as well that affect the FD and CO2 emissions, so this study can be re-studied by considering them. This study focuses only on nineteen low-income countries; the research can be extended by adding more countries. The research can also be expanded by considering the high-income states, and comparative analysis can be conducted. Moreover, the study can be carried forward by using the other regions' dataset or by using a single country dataset.

Authors' contributions Asadullah Khaskheli: conceptualization; writing, original draft; writing, review and editing; data curation

Yushi Jiang: conceptualization; writing, original draft; writing, review and editing; supervision

Syed Ali Raza: methodology; formal analysis; writing, original draft; writing, review and editing; methodology; software

Komal Akram Khan: writing, original draft; writing, review and editing; data curation Muhammad Asif Qureshi: writing, original draft; writing, review and editing; data curation

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

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