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Carbon emissions and the rising effect of trade openness and foreign direct investment: Evidence from a threshold regression model

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A R T I C L E I N F O

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A B S T R A C T

The relationship between carbon emissions, foreign trade openness, and FDI has been studied in prior studies. The previous studies, however, did not examine the link by focusing on carbon emissions in India's industrial sectors. Using carbon emission intensity as a threshold variable and a threshold regression model, we add to the existing studies by assessing the influence of India's industrial sector on carbon emissions. According to the study's findings, there are three threshold effects of foreign direct investment and foreign trade openness on industrial carbon emissions. FDI harms industrial carbon emissions, as it has a characteristically declining and then rising effect coefficient on industrial carbon emissions. Foreign trade openness, however, affects carbon emissions both positively and negatively. Foreign trade openness encourages carbon emission in sectors of the economy with lower carbon emission intensity. However, it also partially constrains it for sectors with high carbon emission intensity. The number of employees, technological innovation, GDP per capita, and economic activity intensity significantly influence carbon emissions in India's industrial sector. This study can extend further in other countries using the recent innovative methodologies.

1. Introduction

The annual increase in carbon dioxide emissions significantly affects global warming. It has an immediate effect on human life and development and the existence of biological species. Moreover, it can bring disastrous results for certain plants and animals. In 2018, the United Nations mentioned that the universe will experience catastrophe by 2040 if global warming is allowed to exceed 1.5 centigrade. Therefore, Global attention has turned to environmental control of pollution and efficient carbon emission. Nowadays, India is the most populous trade nation in the world. According to the India Statistical Yearbook, the overall amount of FDI in 2018 was

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around 885.6 billion INR, while the overall value of imports and exports was 30.51 trillion INR. The fast expansion of global commerce and FDI has significantly aided the development of India's economy, although researchers are worried about its connection to carbon emissions. Significant attempts have been made to analyze the connection between FDI, carbon emissions, and international commerce. These studies provide the below-given characteristics: First, studies on how carbon emissions, foreign trade, and FDI are related mainly examine the connection between foreign trade openness and carbon emissions, between FDI and carbon emissions, or between foreign trade openness and FDI [1,2,3]; [4]). These investigations have, however, not used all these variables together. Second, the previous research ignores India's industrial sector's carbon emissions.

Third, most earlier research predicated a linear connection between carbon emissions, international trade, and FDI. Nevertheless, international trade and foreign trade openness may have various relationships with carbon emissions in industries depending on the varying amounts of carbon emissions. Fourth, different types of data choices, selection of countries, and methodological approaches can produce contradictory views on carbon emissions, international trade openness, and FDI [5,6,7]. For example, Yang and Tian (2017), [8]; and [9] selected different areas, and [10] selected different countries. Moreover, other researchers used diverse methodological approaches, including the panel quantile regression model by Refs. [11,12,13] and [14] and the VECM approach by Refs. [15,16,17]. Due to the differences in the methodological approaches, selection of the variables, and countries, those studies provided different results. This study employs the threshold regression approach to examine the link between foreign direct investment, foreign trade openness, and carbon emissions using the panel data on India's industrial sector consisting of 20 industries.

Along with the studies discussed above, a few recent studies have used the above-discussed variables. For example [18], studied G8 countries to examine the relationship between foreign direct investments, trade openness, energy usage, energy growth, and CO2 emissions. Moreover [19,19], conducted studies in nations working on the Belt and Road initiative. Authors in these countries mainly intended to analyze the nexus between carbon intensity and China's outward foreign direct investment. Moreover [20], examined the nexus between trade openness and environmental degradation in South Africa.

In contrast [11–13,21,22], analyzed the connection between environmental degradation and foreign direct investment in the BRICS countries. However, these recent studies also provide mixed and inconclusive findings. Therefore, exploring the existing literature further and using recent techniques to develop robust findings is highly important.

In light of previous studies, our study makes three significant contributions: First, it aims to examine the connection between carbon emissions, foreign trade openness, and foreign direct investment in the industrial sector in India. Second, this research uses panel data from the national industrial sector, which divides the industries in India into 20 sectors, to examine the effect of FDI and foreign trade openness on the intensity of CO2 emissions. Third, using panel data gathered from 2006 to 2021, a threshold regression technique is employed to investigate the influence of foreign trade openness and foreign direct investment on various intensities of carbon emissions. The fixed-effect approach analyzes the influence of foreign trade openness and foreign direct investment on carbon emissions.

The rest of this essay is structured as follows. The literature review is presented in Section 2, variable descriptions, data sources, and models in Section 3, and the research findings and analyses are covered in Section 4. The last section includes some key findings and study implications.

2. Review of literature

After searching the existing literature, this study finds that the research on carbon emissions, foreign trade openness, and foreign direct investment can be loosely split into three groups. (1) Examine the effects of FDI on the environment to determine whether a country is truly a "pollution haven," (2) Examine the effects of foreign trade openness on carbon emissions, and (3) Examine the connection between foreign trade openness and FDI.

There are numerous channels through which foreign direct investment affects the environment. These channels can be divided into three components: One theory holds that FDI directly causes and manifests "pollution havens." A pollution haven hypothesis was proposed in light of the disparities in environmental control policies among various nations. Usually, emerging economies have no focus on environmental regulations or focus with less rigor, whereas industrialized economies follow stringent environmental guidelines. Due to this movement in CO2 emissions from industrialized to emerging economies, some developing nations face higher carbon emissions [23]. used a panel cointegration approach on the panel data from 1980 to 2007. They examined the effects of financial development and industrial growth on environmental deterioration using. Their findings confirm the "pollution haven" hypothesis [24]. used GMM's two-step estimating method on the panel data to examine the impacts of per capita income, exports, imports, trade openness, and foreign direct investment on carbon dioxide emissions. Their findings indicate that significant infusions of foreign direct investment increase CO2 emissions. The second point of view, "Pollution Halo," contends that entering foreign direct investment introduces cutting-edge managerial ideas and technology, improving the atmosphere. A panel correction standard error (PCSE) model was created by Yu and Xu (2019) using data from the Chinese provincial panel (2000–2017). (1) The research revealed that FDI reduces domestic Carbon dioxide emissions. Regionally, CO2 emissions are inversely associated with the coefficients in the western, central, and eastern areas. (2) CO2 emissions at the regional and national levels have significantly increased as a result of development and internal research. The third point of view is that whether there is or no existence of a "pollution halo" or "pollution haven" depends on the level of growth in the economy. According to the "pollution haven" theory, more FDI may cause more pollution in the initial phases of economic growth. According to the "pollution halo" hypothesis, FDI indirectly lowers environmental damage throughout economic development through technological innovation.

The primary goal of the existing studies is to examine how foreign trade affects carbon emissions across various locations and categories. From the viewpoint of the effect, Grossman and Krueger split the environmental outcomes into three categories: technical effect, composition effect, and scale effect. This categorization has been extensively employed to analyze the relationship between environment and trade studies. Yan and Yang (2010) calculated the intensity of CO2 emission present in China's international trade from 1997 to 2007. They discovered that composition and scale impacts raised the CO2 emissions due to the trade, whereas technical impacts somewhat countered it. Trade surplus and deficit are two categories for imports and exports [25,26,27]. [24] employed the input-output analysis method using data from 2000 to 2010. They conducted a study to calculate the carbon dioxide emissions for international trade in India. They concluded trade surplus in India was the primary cause of the sharp rise in CO2 emissions.

Exports and Imports are the two categories of international trade. Using the data from 2000 to 2016, Sulaman et al. (2020) investigated the effects of global trade along the "Belt and Road" program on CO2 emissions. According to the research, trade in both high- and low-income nations decreased carbon emissions but raised CO2 in developed nations. Moreover, low-income nations have seen an increase in imports, whereas high- and middle-income nations have seen a drop in imports which causes an increase in CO2 emissions [28]. evaluated the effect of Turkey's exports on CO2 emissions in several places. The research concluded that a rise in exports does not significantly affect CO2 emissions, whereas a decrease in exports significantly reduces CO2 emissions. While using data from 1980 to 2014, Chen (2018) investigated the connection between foreign trade openness and per-capita carbon dioxide (CO2) emissions in India and concluded that trade openness reduces carbon dioxide emissions. [5,6]; and [29] broke down the environmental Kuznets curve into the scale, composition, and technology effects to analyze the effect of trade openness on US carbon emissions. Their research concluded that carbon dioxide emissions were lowered due to trade openness.

Most research on the interaction between FDI and foreign trade has been on substitution and complementarity effects. The relationship is complementary between FDI and foreign trade when the cost of foreign trade is above the average. On the contrary, there is a substitution effect when the cost of foreign trade is below the average (José, 2007). Findings by Ref. [30] indicate that FDI helps advance global trade. Since FDI and foreign trade are distinct notions about various nations and business sectors, the existing literature does not provide solid conclusions about their relationship. [31–33]; and Jensen and Camilla (2004) concluded that FDI is a primary determinant of trade between nations in Central and Eastern Europe and the European Union.

Nevertheless, studies have also been conducted in other countries to examine the effect of FDI and found different effects on foreign trade [34]. and Wong et al. (2007) conducted a study in Singapore and observed the feedback link between FDI and the total volume of services exchanged. They also found similar results on the relationship between service imports and FDI. Nonetheless, for Malaysia, there is a weak two-way causal link. In contrast [35,36], found the opposite results.

In other words, fewer studies have investigated the relationship between industrial carbon emissions, FDI, and trade openness in India. The relationship between foreign trade openness, foreign direct investment, and industrial carbon emissions in India must be investigated. While employing the panel data for India's industrial sector from 2006 to 2021, a threshold panel regression technique is used to analyze the impact of foreign trade openness and foreign direct investment on India's carbon emissions.

3. Description of data and model construction

3.1. Description of data and variables

The study sample used in this work comprises sixteen years of data from 20 industry sectors. The industrial sector in India is classified into 20 industries following the continuity and matching of the data and industry classification approach based on the "India Input-Output Table." Moreover, various other industry standards have also been applied for this classification. These 20 industries primarily include metal smelting and rolling processing industry, power, coal mining and washing industry, thermal production and supply industry, metal ore mining and processing, papermaking printing, cultural and educational sports goods manufacturing industry, and refining, electrical machinery and equipment manufacturing industry, electrical machinery and equipment manufacturing industry, general-purpose, special equipment manufacturing industry, transportation equipment manufacturing industry, computer and other electronic equipment manufacturing industry, communication equipment, wood processing and furniture manufacturing industry, instrumentation and cultural office machinery, manufacturing, petroleum and natural gas mining industry, metal products industry, non-metallic ore mining and other mining and processing industry, handicrafts and other manufacturing (waste and scrap), food manufacturing and tobacco processing industry, clothing shoes hat leather and down and its products industry, chemical industry, textile industry, petroleum processing, coking and nuclear fuel processing industry, and non-metallic mineral products industry.

Twenty sectors' worth of data from 2006 to 2021 are used in this study. The "India Science Statistical Yearbook" (2006–2021) database is used to extract data for Industrial research and development (R & D), and the "India Energy Statistical Yearbook" (2006–2021) database is used to get the data for energy consumption at the industry level. Finally, the "India Environmental Statistics Yearbook" (2006–2021) database collects the industry emissions data. Additionally, the "India Science and Technology Statistical Yearbook" (2006–2021) database is employed to collect the data for R&D spending, while the "India Statistical Yearbook" (2006–2021) database is used to get the data for total exports and imports, GDP, foreign direct investment. Moreover, the data for the number of employees and total output value are also taken from this source.

3.1.1. The dependent variable (threshold variable)

$CDE_{i,t}$ shows the intensity of CO2 emission for sector i at time t. The overall industry carbon emissions ratio to the industry's output value yields the industry's carbon emission intensity. The sum of the emission coefficient and energy used in the industry results in overall carbon emissions.

3.1.2. Independent variables

$FDI_{i.t}$ indicates the foreign investment made for sector *i* at time *t*. The indicators evaluating the effects of FDI on industrial carbon emissions are chosen based on the availability of data and collinearity issues observed in econometric analysis [37]. The FDI inflows into the industrial sector of India increase carbon emissions pollution. The FDI inflows cause a rise in CO2 emissions in developing countries, whereas it causes a reduction in CO2 emissions in advanced economies. According to the technological spillover effects, the energy efficiency of the host country and the technological level will rise due to increased foreign direct investment. In this case, India's industrial sector has attracted foreign direct investment to reduce carbon emissions.

$FTO_{i.t}$ depicts the foreign trade openness in sector *i* at time *t*. The reliance level of foreign trade openness (the ratio of total exports and imports in India to total gross domestic product) can more accurately depict the connection between economic growth and trade economic openness in India. The primary source of environmental stress is exports [38]. The ratio of total exports and imports to total production value was used to gauge how open the Indian industrial sector is to foreign trade. If there is a positive calculated coefficient of trade openness, an increase in the openness of the industrial sector in India will result in higher carbon emission pollution. Suppose there is a negative predicted coefficient, on the other hand. In that case, opening up the industrial sector in India to free foreign trade will assist in reducing carbon pollution.

3.1.3. Control variables

$Y_{i.t}$ denotes the per capita GDP index for sector *i* at time *t*. The amount and scope of economic development in an industry strongly correlate with its carbon dioxide emissions. The relationship between carbon emission and economic development is measured using the per capita GDP index (Sbia et al., 2014). The Environmental Kuznets Curve (EKC) predicts that once the threshold is achieved, environmental pollution will be reduced by economic growth. The deterioration of the growth of the economy and the environment go hand in hand. According to Ref. [39] concluded that there is an inverse U-shaped connection between economic growth and carbon emissions. However, EKC's claims have not been supported when the industrial share represents the country's economic structure. In this case, studies suggest that there could be a U-shaped association between carbon emissions and industrial economic growth.

$TEC_{i.t}$ indicates the technological innovation index for sector *i* at time *t*. In an open economy, domestic and foreign sources contribute to low-carbon technological advancement in the local population. Outside channels allude to global technologies, whereas domestic channels belong to independent technological innovation. The capacity of local businesses to integrate and utilize foreign technology is just as important as global technology import and independent technological innovation for the development of the local nation's environmental protection and production technology levels. Technological patent transfer, cross-border investment, and trade agreements are all examples of ways to import technology, with cross-border investment being the most obvious method. The relationship between foreign direct investment and TEC is used to measure how well local businesses can absorb technology brought about by foreign direct investment. The stimulated technology demonstrates how domestic companies must demonstrate a certain level of knowledge capacity in order to benefit from international technology spillovers. It also emphasizes the critical role that foreign businesses play in encouraging domestic businesses to innovate independently and reduce emissions. The innovative patent authorization data, which shows a significant degree of technical innovation extent, is recognized as autonomous technological innovation data based on the findings of [40,41].

$PE_{i.t}$ shows how many workers were there in sector *i* at time *t*. While drafting workforce and industrial environmental protection regulations, the government should consider the number of industry employees. The workforce influences carbon emissions in the sector.

$TOR_{i.t}$ indicates the level of R&D in sector *i* at time *t*, which significantly influences how carbon emission technology is reduced in the industrial sector. Research and development funds are frequently employed to gauge the activity level [24]. This study uses the industry-related R & D expenditures to total output ratio to quantify the collinearity and endogeneity issues.

$TOR_{i.t}$ represents the activity levels of the economy in sector *i* at time *t*. The activity levels of the economy in the ACT indicate the sector's output level. The amount of carbon emissions increases with industry business growth. The amount of power consumed can be compared to the activity levels of the economy (see Table 1).

Table 1
Variables and their description.

Variable	Variable Type	Description	Measurement unit
$FTO_{i,t}$	Independent variable	the ratio of the industrial industry's total exports and imports to its overall output	%
$FDI_{i,t}$	Independent variable	the proportion of output value to the absolute index of foreign-funded firms' output value	%
$Y_{i,t}$	Control variable	GDP per capita	Ten thousand INR/person
$TEC_{i,t}$	Control variable	Amount of patents for inventions with a high level of innovation	Piece
$PE_{i,t}$	Control variable	Industry employees	Ten thousand
$ACT_{i,t}$	Control variable	Power consumption	10,000 kW h
$CDE_{i,t}$	Threshold variable (Dependent variable)	Total carbon emissions to output value ratio	%

3.1.4. Summary statistics of the variables

Data on carbon emissions from the Indian sectors were used to create descriptive statistics prior to the empirical analysis and model design. Table 2 displays the findings of descriptive statistics for all factors.

As Table 2 demonstrates: The standard deviation carbon emission intensity is 0.819971, the minimum value is 0.0830246, the maximum value is 5.022769, and the change in value from maximum to minimum is around 4.9. This significant change in the values indicates that the severity of carbon emissions varies significantly among different sectors. The discrepancy between various sectors can also be observed in other variables. The difference between the maximum and minimum value for foreign direct investment of 20 sectors is 7.8. Moreover, the change in the maximum from the minimum value of foreign trade openness is 968.3. Therefore, the industrial sector must be divided based on the intensity of its carbon emissions to examine the effects of foreign direct investment and openness to foreign trade on industrial carbon emissions in India.

In 2010, 20 industries' carbon emission data of intensity were chosen, and they were then reorganized in ascending order. The intensity of carbon emission intensity in 2010 differed widely across sectors, as shown in Fig. 1, and nearly fell into four unique intervals: (0.1184, 0.4689), (0.4689, 1.0496), (1.0496, 2.2276), and (2.2276, 2.2706). It indicates that the effect of foreign trade openness and foreign direct investment on carbon emissions has a threshold effect over varying intensities of carbon emissions (see Fig. 2).

3.2. Development of the model

This study further splits the industrial sectors of India into different intervals due to the substantial disparities in carbon emissions across various sectors. This study applies the carbon emission decomposition factors based on the STIRPAT approach suggested by Richard and Kaya (1989) for an econometric analysis to examine the influence of carbon emissions.

$$CDE_{i.t} = \alpha_0 + \alpha_1 FDI_{i.t} + \alpha_2 FTO_{i.t} + \alpha_3 X_{i.t} + \varepsilon_{i.t} \quad (1)$$

Using foreign trade openness and FDI as our primary variables, we examine the link between carbon emissions, foreign trade openness, and foreign direct investment. Nevertheless, foreign trade openness, FDI, and other variables like per capita output and technological innovation affect carbon emissions. The control variables selected in this study to control the relevant industry structure are economic activity intensity, industry R & D intensity, and the number of industry employees. This study uses the natural logarithm of the variables to counteract heteroscedasticity in the data. The model mentioned above has been modified in the following ways:

$$CDE_{i.t} = \beta_0 + \beta_1 FDI_{i.t} + \beta_2 FTO_{i.t} + \beta_3 lnY_{i.t} + \beta_4 FDI_{i.t} * lnTEC_{i.t} + \beta_5 lnPE_{i.t} + \beta_6 TOR_{i.t} + \beta_7 LnACT_{i.t} + \varepsilon_{i.t} \quad (2)$$

This study uses foreign trade openness and foreign direct investment as independent variables. Moreover, the carbon emission intensity utilized in this study is considered a threshold variable. This threshold variable helps to construct the Panel threshold model since the fixed effect approach is only used to determine the linear association among carbon emission intensity, foreign trade openness, and foreign direct investment. The panel threshold model is shown below:

$$CDE_{i.t} = \alpha_0 + \alpha_1 FDI_{i.t} * I(CDE_{i.t} \le \Upsilon_1) + \alpha_2 FDI_{i.t} * I(CDE_{i.t} > \Upsilon_1) + \Phi_1 X_{i.t} + \varepsilon_{i.t} \quad (3)$$

$$CDE_{i.t} = \beta_0 + \beta_1 FTO_{i.t} * I(CDE_{i.t} \le \Upsilon_2) + \beta_2 FTO_{i.t} * I(CDE_{i.t} > \Upsilon_2) + \Phi_2 X_{i.t} + \varepsilon_{i.t} \quad (4)$$

4. Results discussion

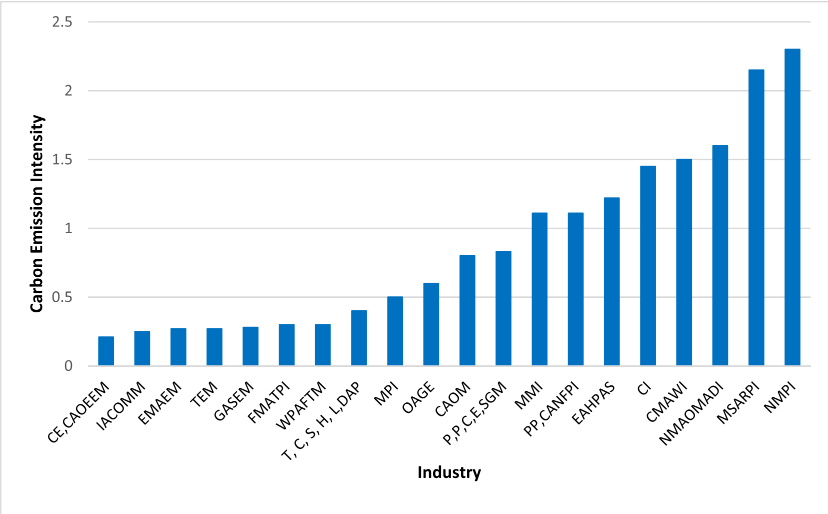
4.1. Linear regression

4.1.1. Stationarity test

The data in this study is collected from 20 industrial sectors of India from 2006 to 2021. Our study uses panel data which contains the properties of both cross-sectional and time series. It is necessary to check the stationarity in the panel data since the panel data is usually nonstationary. The unit root tests employed in this study to check the stationarity of the panel data are LLC, PP, and ADF. Our findings based on these unit root tests indicate that variables are nonstationary at levels, whereas all the variables are stationary once the first difference is taken. Table 3 displays the test results.

Table 2
Summary statistics of the variables.

Variable	Sample value	Mean	Standard deviation	Minimum	Maximum
CDE	315	1.021	1.528	0.215	4.595
FDI	315	3.215	1.548	1.251	8.584
FTO	315	71.524	170.584	1.575	1022.586
LNY	315	3.874	1.239	1.986	6.958
FDI*TEC	315	511.541	1251.541	0.125	11258.25
LNPE	315	6.514	1.128	4.158	8.854
TOR	315	1.201	1.251	1.536	1.287
LNACT	315	7.125	1.251	4.257	9.856



Note: in Figure 1, NMPI denotes the non-metallic mineral products industry, MSARPI is used for metal smelting and rolling processing industry, NMAOMADI stands for non-metallic mines and other mining and dressing industry, CMAWI for coal mining and washing industry, CI stands for the chemical industry, EAHPAS stands for energy and heat production and supply, PP stands for petroleum processing, and CANFPI is used for coking and nuclear fuel processing industry, MMI stands for metal mining industry, P,P,C,E,SGM denoted papermaking, printing, culture, education, and sports goods manufacturing, CAOM is used to denote crafts and other manufacturing (waste and scrap), OAGE stands for oil and gas extraction, MPI denoted Metal products industry, T, C, S, H, L, and DAP stand for textile, clothes, shoes, hats, leather, down, and by-products, WPAFTM is used to indicate Wood processing, and furniture manufacturing, FMATPI stands for Food Manufacturing and Tobacco Processing Industry, GASEM stands for general and special equipment manufacturing, TEM stands for transportation equipment manufacturing, EMAEM is used to show denotes electrical machinery and equipment manufacturing, IACOMM is used to show instrumentation and cultural office machinery manufacturing CE, CAOEEM denotes communication equipment, computer and other electronic equipment manufacturing.

Fig. 1. Intensity of the carbon emissions in 2010 for 20 industries
Note: in Fig. 1, NMPI denotes the non-metallic mineral products industry, MSARPI is used for metal smelting and rolling processing industry, NMAOMADI stands for non-metallic mines and other mining and dressing industry, CMAWI for coal mining and washing industry, CI stands for the chemical industry, EAHPAS stands for energy and heat production and supply, PP stands for petroleum processing, and CANFPI is used for coking and nuclear fuel processing industry, MMI stands for metal mining industry, P,P,C,E, SGM denoted papermaking, printing, culture, education, and sports goods manufacturing, CAOM is used to denote crafts and other manufacturing (waste and scrap), OAGE stands for oil and gas extraction, MPI denoted Metal products industry, T, C, S, H, L, and DAP stand for textile, clothes, shoes, hats, leather, down, and by-products, WPAFTM is used to indicate Wood processing, and furniture manufacturing, FMATPI stands for Food Manufacturing and Tobacco Processing Industry, GASEM stands for general and special equipment manufacturing, TEM stands for transportation equipment manufacturing, EMAEM is used to show denotes electrical machinery and equipment manufacturing, IACOMM is used to show instrumentation and cultural office machinery manufacturing CE, CAOEEM denotes communication equipment, computer and other electronic equipment manufacturing.

Cointegration among the variables is checked using Kao and Pedroni tests. This study's variables tested for cointegration are LNPE, TOR, FDI * TEC, FTO, LNY, LNACT, CDE, and FDI. Past studies like [16,17] also used the Kao and Pedroni tests and obtained the cointegration among the variables studied in emerging countries.

Table 4's cointegration test results show the long-run connection between industry economic activity intensity, independent technological innovation, GDP per capita, foreign trade openness, the number of employees, foreign direct investment, and industry R & D intensity. The long-run connection exists across all industry sectors in India.

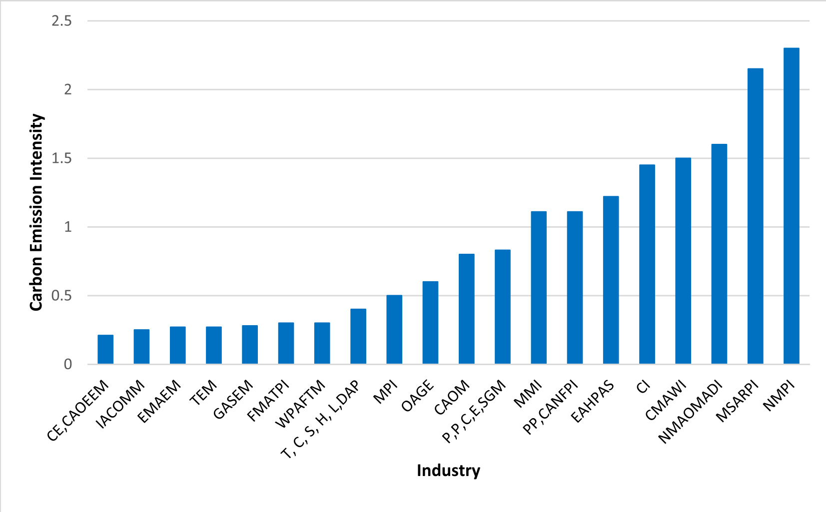
4.1.2. Model selection for panel regression

The most common models in panel data are mixed, random, and fixed-effect models. The best approach in these models should be chosen after comparing these models with each other. The Hausman test, LM test, and F test are used as comparisons in this study. The fixed-effect model and the mixed utility models are often compared using the F test. In contrast, the random and mixed-effect models are compared using the LM test, and the random and fixed-effect models are compared using the Hausman test.

Table 5 demonstrates that the null hypotheses are rejected using all three tests for all industries, including highly polluting industries. As a result, the fixed-effect model outperforms the mixed-effect model, whereas the random-effect model outperforms the mixed-effect model. As opposed to this, the fixed-effect model is preferable to the random-effect model, making it the best option.

4.1.3. Regression using fixed effect model

In order to conduct the research, control variables are introduced to the fixed-effect model. Table 6 shows significant findings for foreign direct investment at a 10% significance level, demonstrating that it significantly affects carbon emissions. When the control variables are added, the coefficient for the FDI effect on carbon emissions varies from negative to positive and then becomes negative again. It indicates that the effect of FDI on Carbon emissions is complicated and requires additional investigation. Moreover, no correlation is found between carbon emissions and foreign trade openness. However, these results are different from the findings of the



Notes: For further details about the variables, please refer Notes to Figure 1.

Fig. 2. Intensity of the carbon emissions in 2021
Notes: For further details about the variables, please refer Notes to Fig. 1.

Table 3
Findings of the stationarity tests.

Variables	Values at level			Values at first difference		
Index	LLC test	ADF test	PP test	LLC test	ADF test	PP test
CDE	−21.512***	210.548***	310.258***	−21.251***	99.548***	88.586***
FDI	−9.528***	150.584***	198.558***	−5.541***	102.524***	99.845***
FTO	−9.587***	170.589***	251.541***	−10.547***	151.524***	165.562***
LNY	−9.874***	51.546	29.856	−12.546***	125.548***	154.529***
FDI*TEC	22.548	1.548	2.748	−8.846***	92.638***	210.521***
LNPE	−9.899***	91.548***	100.254***	−6.854***	78.562***	89.965***
TOR	7.856	4.541	9.658	−5.845***	70.859***	79.958***
LNACT	−9.847***	99.845***	49.748*	−8.845***	84.548***	90.856***

Note: In this Table, a 1% significance level is indicated by ***, ** indicates a 5% significance level, and * indicates a 10% significance level.

Table 4
Panel data cointegration techniques.

Testing Method	Kao test UDF	ADF	Pedroni test PP	MPP
Statistics	−4.854***	−10.514***	−11.541***	12.584***

Note: In this Table, a 1% significance level is indicated by ***, ** indicates a 5% significance level, and * indicates a 10% significance level.

Table 5
The test results for selecting the relevant panel models.

Test type	Hausman test	LM test	F test
Findings	−12.524***	−9.857***	13.548***

Note: In this Table, a 1% significance level is indicated by ***, ** indicates a 5% significance level, and * indicates a 10% significance level.

past literature. The inconsistent findings may be since the impact changes during different periods, which may cancel each other out. Therefore, more investigations are needed using a threshold regression model.

Moreover, the findings related to the control variables indicate that, excluding research and development intensity, the remaining control variables significantly affect carbon emissions [42,43]. also introduced the control variables in their research conducted in the US, UK, and other developed countries to consider the fixed effects. They concluded that control variables had a significant effect on carbon emissions.

In conclusion, this research utilizes a threshold regression model to test the impact of foreign trade openness and foreign direct

Table 6
Panel regression models based on the fixed effects.

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6
FDI	0.584***	−0.125***	0.412***	−0.458*	−0.415*	−0.415*
FTO	−0.015	0.014	0.142	−0.147	−0.125	−0.145
LNY		−0.875***	−0.854***	−0.965***	−0.985***	−1.5412***
FDI*TEC			0.0412*	0.125*	0.147*	0.542*
LNPE				−0.984***	−0.851***	−2.548***
TOR					7.584	7.856
LNACT						0.684***
CONS	0.514***	5.584***	4.584***	12.542***	13.529***	15.541***

Note: In this Table, a 1% significance level is indicated by ***, ** indicates a 5% significance level, and * indicates a 10% significance level.

investment on carbon emissions across various ranges. Moreover, this research examines the association between these variables across different ranges.

4.2. Threshold regression

4.2.1. Foreign direct investment is used as an independent variable

Examining the total number of thresholds is necessary before using any model. Hence, this study uses the self-sampling technique to test the triple, double, and single thresholds. The bootstrap technique is typically used to calculate P and F values by using a sampling number equivalent to 1000 times. However, other researchers like [44] and [45–47] conducted studies in advanced economics and found contradictory results. The possible reason for the differences in these results could be that those studies did not consider the various thresholds.

Table 7 demonstrates that all three thresholds—triple, double, and single—are significant at a 1% significance level. Thus, there will be a triple threshold to analyze the effect of foreign direct investment on the intensity of carbon emission when the threshold variable used is carbon emission intensity. In the next step, this study applies the triple threshold model. The first step is to run the threshold regression by calculating the threshold value. Table 8 displays the findings of the threshold value, whereas Table 9 displays the threshold regression result.

Tables 8 and 9 demonstrate that the amount of FDI has a detrimental and nonlinear effect on the intensity of carbon emissions. Four categories can be used to categorize the impact of various scales of FDI on the intensity of carbon emissions. The scale of foreign direct investment has a significant effect on carbon emissions in these four ranges. An increase in the amount of FDI decreases the intensity of carbon emission when the intensity of carbon emission is less than 0.1876. When carbon emission intensity ranges from 0.1876 to 1.3364, FDI has an average efficiency of −28.77. When carbon emission intensity ranges from 0.1876 to 1.3364, FDI marginal efficiency drops below −36.5897.

Moreover, when carbon emission intensity ranges from 1.3364 to 2.2825, FDI marginal efficiency increases to −23.4899. Finally, when the intensity of carbon emission rises above 2.2825, the marginal efficiency of foreign direct investment becomes 0. Hence, the size of the effect of FDI is highest on the intensity of carbon emission when the intensity of carbon emissions is between [0.1876, 1.3364].

4.2.2. Foreign trade openness is used as an independent variable

Table 10 shows the outcomes of the *P*-values and f-values obtained using the Bootstrap procedure. The P value is 0.000 when the single-threshold model is used, meaning that the value is found significant at a 1% significance level. The P value is 0.002 when the double-threshold model is used, meaning it is also significant at a 1% significance level. Finally, the p-value is 0.046 when the triple threshold test is employed, suggesting that this value is significant at a 5% significance level.

It can be observed from Tables 9 and 11 that there are four distinct intervals through which foreign trade openness significantly affects the intensity of carbon emissions. Foreign direct investment has marginal efficiency of −0.9478 when carbon emission intensity is below 1.6067. Moreover, foreign direct investment has marginal efficiency of 0 when carbon emission intensity ranges from 1.6067 to 2.0122. In addition, foreign direct investment has a marginal efficiency of 0.9605 when carbon emission intensity ranges from 2.0122 to 2.2825. These results show that when the intensity of carbon emission is below 1.6067, the intensity of carbon emissions reduces when foreign trade openness increases.

Moreover, the intensity of carbon emissions rises as trade openness increases; with an intensity of carbon emissions above 2.2825,

Table 7
Sampling tests for selecting the number of thresholds.

Explained Variable	Explanatory variable	Threshold Variable	Threshold	*P*-value	Confidence Interval			F value
					1%	5%	10%	
CDE	FDI	CDE	Triple Threshold	0.00	7.125	4.412	2.874	21.541
			Double Threshold	0.00	7.471	4.745	2.896	40.458
			Single Threshold	0.00	9.584	4.985	3.362	87.521

Table 8
Results based on the threshold regression.

Threshold Variable	Independent variable	Dependent Variable	Threshold	Estimate	95% Confidence Interval
			Triple Threshold	0.215	[0.174, 0.347]
				1.541	[1.325, 1.548]
				3.142	[2.251, 2.458]
CDE	FDI	CDE	Double Threshold	1.412	[1.254, 1.587]
				2.412	[2.354, 2.456]
			Single Threshold	2.745	[2.358, 2.415]

Table 9
Findings based on the threshold regression.

Variable	Dependent Variable: FDI	Variable	Dependent Variable: FTO
FTO	−0.145***	FTO	1.528***
LNY	−1.541***	LNY	−1.5489***
FDI*TEC	0.025***	FTO*TEC	0.054***
LNPE	−1.584***	LNPE	−1.584***
TOR	4.587	TOR	5.965
LNACT	1.541**	LNACT	1.485*
FDI1	−31.526***	FTO1	−1.541***
FDI2	−41.459***	FTO2	0.051
FDI3	−31.545***	FTO3	1.524***
FDI4	0.014	FTO4	3.658***
CONS	22.548*	CONS	−4.584

Note: In this Table, a 1% significance level is indicated by ***, ** indicates a 5% significance level, and * indicates a 10% significance level.

Table 10
Threshold effects using self-sampling test.

Threshold variable	Independent variable	Dependent variable	Threshold	Confidence Interval			F value	P value
				1%	5%	10%		
CDE	FDI	CDE	Triple Threshold	9.541	4.521	3.251	4.584	0.035
			Double Threshold	−2.152	10.251	−21.524	21.564	0.010
			Single Threshold	8.521	4.528	2.548	91.584	0.010

Table 11
Findings based on the threshold regression.

Threshold variable	Independent variable	Dependent variable	Threshold	Estimate	95% Confidence Interval
CDE	FDI	CDE	Triple Threshold	2.514	[2.142, 2.541]
				1.856	[0.145, 1.742]
				2.548	[2.541, 2.451]
			Double Threshold	2.845	[2.545, 2.845]
				1.741	[1.748, 2.235]
			Single Threshold	2.235	[2.145, 2.754]

the marginal efficiency increases to 2.8571. There is a most significant effect of trade openness on the intensity of carbon emissions when the intensity of carbon emissions exceeds 2.2825. Foreign trade openness explicitly reduces carbon emissions when the intensity of carbon emissions is low. Opening up trade will, however, to some extent, increase carbon emissions as the intensity of emissions rises.

According to estimates based on the fixed effect, there is no significant linear effect of foreign trade openness on carbon emissions in the industrial sectors of India. These results contradict most previous research that found a substantial relationship between carbon emissions and foreign trade openness. For instance Ref. [48], studied the India-Australia trade. They found that CO2 emissions increase due to increased foreign trade openness. [42,43,6,44]; and [29] conducted a study in the context of the US, Canada, and other advanced and developing countries. Their findings indicate that foreign trade openness causes a reduction in CO2 emissions. Moreover, their findings demonstrated that technology spillovers might dramatically lower particular trade Carbon dioxide emissions, whereas CO2 emissions related to renewable energy consumption decrease due to foreign trade openness.

On the other hand, foreign direct investment and foreign trade openness significantly affect CO2 emissions. According to a threshold regression approach, foreign direct investment and foreign trade openness have varying effects on CO2 emissions over different intervals of carbon emissions. The threshold regression model also depicts that linear regression may cancel out the negative and positive links among the variables over different periods and ranges. Therefore, the threshold regression is more suitable than the linear regression approach for foreign direct investment and foreign trade openness effect on the CO2 emissions for industrial sectors of India. The authors like [49] and [6,45,46] conducted studies in advanced countries. They concluded the significant effect of foreign direct investment and foreign trade openness on CO2 emissions.,

5. Conclusion and policy recommendations

This research uses the panel threshold model to investigate the effect of trade openness and foreign investment on carbon emissions. For this purpose, this study uses sixteen years of data from 20 industrial sectors of India. Our research provides the following conclusions based on the analysis:

We partially corroborate the pollution halo theory by finding the negative impact of FDI on carbon emissions. The panel threshold model's findings reveal a nonlinear correlation between carbon emissions and foreign direct investment, and the effect of foreign direct investment varies depending on the various levels of the intensity of carbon emission. FDI, however, reduces India's manufacturing sector's overall carbon emissions. The effect of foreign direct investment on carbon emissions is most incredible when the intensity of carbon emissions is between [0.1876, 1.3364].

Trade openness's effects on carbon emissions can be either negative or positive. With an increase in the levels of carbon emissions, the coefficient impact also changes from unfavorable to favorable. Trade openness has a coefficient of −0.95 when the intensity of carbon emission lies between [0.0830, 1.6067]. This coefficient is 0 when the carbon emission intensity lies between [1.6067, 2.0122]. Moreover, this coefficient is 0.96 when the intensity of carbon emission lies between [2.0122, 2.2825]. Finally, this coefficient is 2.86 when the intensity of carbon emission lies between [2.2825, 5.0228]. It indicates that foreign trade openness will limit carbon emissions to some degree. In contrast, the intensity of carbon emissions is negligible, and it will encourage carbon emissions as the intensity of carbon emissions increases.

The economic activity intensity is significant at a 5% significance level, while other indicators, like the number of employees in the sector, technological innovation, and per capita GDP, are significant at a 1% significance level. Moreover, carbon emissions are significantly impacted by economic activity intensity. Among these, the coefficient for the number of employees in the sector and GDP per capita are negative. It shows that a rise in the number of employees in the sector and GDP per capita reduces the carbon emissions in the industrial sectors of India.

The key policy recommendations of the study are:

The scientific findings demonstrate the complexity of the relationship between carbon emissions in the industrial sectors of India and foreign trade openness. The relationship between carbon emission and other variables is quite complicated. These variables affect reducing and increasing carbon emissions in India's industrial sector. Policies should be devised to promote foreign trade openness, reduce carbon emissions in India's industrial sector, and optimize alternative measures to increase foreign trade openness. Moreover, additional measures should be taken to increase foreign trade openness in India. These measures include changing the industry activities that depend heavily on labor to those that depend heavily on technology. Moreover, these changes include "made in India" to "created in India." Likewise, there is still a need to improve the framework of foreign trade openness to increase the exports of industries that are technology intensive.

Similarly, more FDI is necessary for the context of India. It is essential to increase the FDI in sectors with low CO2 emissions and decrease FDI in sectors with high carbon emissions. Therefore, implementing pertinent policies is required to support FDI, accelerate the transfer of cutting-edge global technology, and maximize the benefits of environmental improvement due to technological spillovers. If these policies are implemented successfully, India will eventually attain a low-carbon economy and economic development. For that circumstance, it is crucial to progressively change the global trade and FDI framework while implementing "supply-side reform" in industries with a low focus on carbon emissions. Moreover, new technologies for protecting the environment are being researched and developed simultaneously to establish a green industrial environment.

In order to mitigate the carbon emission in sectors with high carbon emissions and to enhance the restriction of foreign trade openness and foreign direct investment in those sectors with a low intensity of CO2 emissions, multiple subsidized actions may be taken. In the manufacturing sectors, there are segments of visible CO2 emission intensity in 20 different sectors, and the threshold needs to be considered. For industrial sectors with varying degrees of CO2 emissions, different export tariffs and tax rebate policies are usually employed.

This study contributes to the existing literature. However, it is not free from the limitations. The same study can also be conducted in other developing and advanced economies. Moreover, other techniques can also be applied to get the robustness of the results. Similarly, the time series data can also be used to conduct the study.

Author contribution statement

Omer Faruk Derindag: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Alina Maydybura: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Akash Kalra: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Wing-Keung Wong: Performed the experiments; Analyzed and interpreted the data.

Bisharat Hussain Chang: Contributed reagents, materials, analysis tools or data.

Data availability statement

Data will be made available on request.

Declaration of interest's statement

The authors declare no competing interests.

Declaration of competing interest

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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