



# An empirical study on correlation among poverty, inclusive finance, and CO<sub>2</sub> emissions in China

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## Abstract

This paper explores the nonlinear relationship between poverty and CO<sub>2</sub> emissions based on the panel data of 30 provinces in China from 2005 to 2019. In this study, the autoregressive distributed lag (ARDL) model is first used. Findings confirm that poverty has a negative impact on CO<sub>2</sub> emissions in the short run and a positive impact in the long run, while both effects of inclusive finance on CO<sub>2</sub> emissions are negative. In order to explore the reasons for the change in the coefficient of poverty, we introduce a moderating effect (ME) model and a dynamic panel threshold (DPT) model. The result shows that the negative effect of poverty on CO<sub>2</sub> emissions diminishes with the moderation of inclusive finance. When inclusive finance crosses the threshold value ( $IFI=0.2696$ ), the impact of poverty on CO<sub>2</sub> emissions will change from negative to positive gradually, which verifies the applicability of the “Poverty-CO<sub>2</sub> Paradox” in China and provides an empirical basis for breaking the “Poverty-CO<sub>2</sub> Paradox.” Consequently, deepening poverty reduction and pushing the region’s inclusive finance to the threshold level are proposed as effective ways to promote CO<sub>2</sub> emission reduction.

**Keywords** Poverty · Inclusive finance · CO<sub>2</sub> emissions · Autoregressive distributed lag model · Moderating effect model · Dynamic panel threshold model

## Introduction

Ending poverty in all its forms everywhere (SDG1: No Poverty) and taking urgent action to combat climate change and its impacts (SDG13: Climate Action) are among the top priorities of the 2030 Sustainable Development Goals

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### Highlights

- The influences of poverty and inclusive finance on CO<sub>2</sub> emissions are analyzed, providing a reference for sustainable development in the post-COVID-19 era.
- A moderating effect model and a newly developed dynamic panel threshold model are used to explore the possible nonlinear relationship between poverty and CO<sub>2</sub> emissions.
- Poverty plays a less important role in reducing CO<sub>2</sub> emissions with the adjustment of inclusive finance.
- The impact of poverty on CO<sub>2</sub> emissions has a single threshold feature with inclusive finance as the threshold variable.

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(SDGs) (Baloch et al. 2020). However, the world is not on the track to achieve the 2030 goals and targets by the beginning of 2020 (United Nations 2020). Apart from the impact of the coronavirus disease 2019 (COVID-19) pandemic, a more important reason is that there are trade-offs among the various SDGs, hindering their simultaneous implementation. With the successful economic development based on the policy of “Reform and Opening,” China became the world’s second-largest economy in 2010. Inclusive finance has been developing continuously in China since 2005, which helped China gain the achievement of eliminating absolute poverty in 2020. The poverty population was cut down by 93 million, which covered above 70% of the global poverty reduction. In addition, it is glad to see that the emission rate of CO<sub>2</sub> in China, the largest carbon emitter since 2005, tended to slow down obviously along with the development of inclusive finance; CO<sub>2</sub> emission increased with an annual increasing rate of 6.7% from 2005 to 2010, while the increasing rate decreased to 1.3% from 2015 to 2020. As the largest developing country, it is so interesting that both “CO<sub>2</sub> emission reduction” and “poverty reduction” interlinked with “inclusive finance” were achieved successfully in the same period, which essentially attracted our attention. As a result, our

present motivation is to clarify the correlation among poverty, inclusive finance, and CO<sub>2</sub> emissions in China.

At present, there is no systematic research on the correlation among China's poverty, inclusive finance, and CO<sub>2</sub> emissions. The literature on poverty-environment nexus can be traced back to Thomas Malthus (1798), who proposed that the poor pay more attention to immediate needs than to the future. This point is supported by Maslow's hierarchy of needs theory; the poor generally have more basic survival needs than the rich. The poor may thus be more willing to survive at the cost of environmental damage (Lumley 1997; Hagerty 1999). Then, a growing debate was divided into the following three perspectives: the traditional view is that poverty is the cause of environmental degradation (WCED 1987; World Bank 1992; Ramphal 1992; Swinton and Quiroz 2003; Khalid 2019); the second view holds that poverty is not necessarily related to the environment or poverty is not always harmful to the environment (Omuta 1988; Holmberg and Thompson 1991; Duraiappah 1998; Ravnborg 2003; Zaman et al. 2011); the third view considers the complexity of the relationship between poverty and environment, and holds that the relationship between poverty and environment will change due to the influence of other factors (Leach and Mearns 1991; Rizk and Slimane 2018). There are literature works on exploring factors such as institutions and urbanization, but there is no relevant literature from the perspective of inclusive finance. According to the EKC theory, an inverted U-shaped relationship exists between per capita income and environmental pollution. Pollution rises with GDP per capita at a low-income level and falls with GDP per capita at a high-income level. Income level is an important factor when studying the poverty-environment nexus. In China, inclusive finance is a tool for poverty alleviation, which can ease the financing constraints of consumers and enterprises, stimulate consumption and investment, and promote economic growth. Thus, inclusive finance can affect income and therefore the poverty-CO<sub>2</sub> emissions nexus. Considering the special background of "CO<sub>2</sub> emission reduction," "the development of inclusive finance," and "poverty reduction" in China at the same time, this paper will carry out an empirical study on how inclusive finance affects the relationship between poverty-CO<sub>2</sub> emissions.

The main research objectives are as follows: (1) to determine the long-term dynamic nexus among poverty, inclusive finance, and carbon emissions; (2) exploring the moderating impact of inclusive finance on the nonlinear relationship between poverty and CO<sub>2</sub> emissions at the overall and heterogeneity levels; and (3) to propose recommendations to achieve a win-win solution between "No Poverty" and "Climate Action" in China.

Our contributions are presented as the following points: (1) there is a novelty which is to introduce inclusive finance as an intermediate to further correlate with both poverty

reduction and CO<sub>2</sub> emissions. (2) The results of this paper not only verify the applicability of the "Poverty-CO<sub>2</sub> Paradox" in China, but also provide an empirical basis for breaking the "Poverty-CO<sub>2</sub> Paradox." This new finding could provide a possible explanation for the contradictory results in the literature. (3) Three models are employed simultaneously to corroborate the nonlinear relationship among the variables in terms of long-run, overall, and heterogeneity, respectively, which provide more reliable and unbiased results than the earlier related studies.

The remainder of this study is organized as follows: the literature review is presented in the "Literature review" section. "Methodology and data" section outlines the methodology and data, and "Results and discussion" section presents results and discussion, followed by conclusions and policy recommendations in the "Conclusions and policy recommendations" section.

## Literature review

For a better understating, the literature review is divided into two sub-sections, in which the first part contains theoretical literature on the poverty-environment nexus and the poverty-CO<sub>2</sub> emissions nexus. In the second part, we discuss empirical literature on the poverty-CO<sub>2</sub> emissions nexus and the inclusive finance-CO<sub>2</sub> emissions nexus.

### Theoretical literature

Many theoretical studies attempt to explore the relationship between poverty and environment as well as explain how poverty affects the environment. They are mainly based on the following three schools of thought: first, poverty is harmful to the environment. The most typical theory in this view is the "poverty-environment trap" proposed by Brundtland (1987). This view is mainly as follows: poverty leads to environmental degradation in developing countries, while environmental degradation exacerbates poverty in turn, which forms a vicious circle. Scholars who support the poverty-environment trap have clarified that the natural environment was considered as a public good without property rights. To survive, the poor often overuse resources in an unsustainable way, which leads to environmental degradation (Durning 1989; Jalil and Mahmud 2009; Masron and Subramaniam 2019). Second, poverty does not always damage the environment. Guha (1989) looked at the case of Amazon's indigenous people against multinational corporations to express the calls of developing countries and regions for the realization of environmental justice; this case shows that the poor can be more concerned about pollution and environmental degradation than the rich. Kurtz (2003) drew the same conclusion: the poor pay more attention to environmental

protection because they confront the environmental hazards caused by poverty every day. Third, the poverty-environment relationship can change due to the influence of other factors. Leach and Mearns (1991) and Duraiappah (1998) have confirmed that the relationship between poverty and the environment is a multidimensional problem, which can be affected socially, economically, politically, demographically, and institutionally.

The above research mainly explored the relationship between poverty and environment theoretically. With the subdivision and deepening of the research, the research on the relationship between poverty and CO<sub>2</sub> emissions has emerged gradually in recent years. Among them, the “Poverty-CO<sub>2</sub> Paradox” is the most typical theory (Collins and Zheng 2015; Rizk and Slimane 2018), which believes that poverty reduction and CO<sub>2</sub> emission reduction are contradictory but interrelated. Reducing poverty through economic growth will worsen the problem of CO<sub>2</sub> emissions caused by production and consumption at the same time (Smith and Lewis 2011). It seems that the two problems of poverty and CO<sub>2</sub> emissions cannot be solved simultaneously. Apart from that, the government and scholars also have tried to seek the conditions and paths for win–win realization. In 2003, the UK government first put forward “Low Carbon Economy” as gaining more economic output by less environmental pollution (UK Department of Trade and Industry 2003). Subsequently, more and more researchers have conducted extensive studies on low-carbon economy (Hourcade and Crassous 2008; Strachan et al. 2008; Dou 2013). Now “Low Carbon Economy” is regarded as a future development model associated with low energy consumption and less pollution facing up with global warming, resource shortage, and environmental pollution was proposed in order to achieve more production, better living standards, more working opportunities, and less poverty.

## Empirical literature

Empirical research is far from a consensus on how poverty affects CO<sub>2</sub> emissions. In order to better understand the relationship between poverty and CO<sub>2</sub> emissions, we can start with the economic growth-environment nexus and the poverty-environment nexus. The most typical method on the relationship between economic growth and environment is the environmental Kuznets curve (EKC) proposed by Grossman and Krueger (1992). They believed that environmental pollution presents an “inverted U” curve characteristic of increasing first and then decreasing with economic growth. Subsequently, many studies have further verified the existence of the EKC phenomenon (Roberts and Crimes 1997; Kasman and Duman 2015). With further in-depth research, the OECD proposed the application of the decoupling theory to the relationship between economic growth and carbon

emissions in 2002. Decoupling aims to explore the influencing factors and conditions to break the link between environmental hazards and economic wealth (Jin et al. 2020; Wang and Zhang 2021a, b). In recent years, research models on the poverty-environment nexus have been expanded to a simple linear regression model (Islam and Abdul Ghani 2018), three-stage least square (3SLS) (Rizk and Slimane 2018; Dhrifi et al. 2020), generalized method of moments (GMM) (Masron and Subramaniam 2019; Khan 2019), autoregressive distributive lag (ARDL) model (Khan and Yahong 2022), and quantile regression (QR) (Koçak et al. 2019).

Based on the above research models, scholars further conducted more empirical research on the poverty-CO<sub>2</sub> nexus. Most of the existing research verified the “Poverty-CO<sub>2</sub> Paradox.” For example, Khan (2019) employed the systematic GMM estimation method and empirically concluded that poverty would aggravate CO<sub>2</sub> emissions in ASEAN countries. Masron and Subramaniam (2019) investigated the positive impact of poverty on CO<sub>2</sub> by using the data of 50 developing countries and the GMM method. Baloch et al. (2020) confirmed that there is a positive relationship between poverty and CO<sub>2</sub> emissions in Pakistan. However, the “Poverty-CO<sub>2</sub> Paradox” was argued by Koçak et al. (2019). He deduced that poverty suppressed CO<sub>2</sub> emissions at all quantile levels based on panel quantile regression method and panel data of 48 sub-Saharan countries from 2010 to 2016. Contrary to all these above views, Rizk and Slimane (2018) announced that the institutional quality played a positive role in reducing poverty and CO<sub>2</sub> emissions based on a 3SLS model, which explored a new field to study the factors influencing the poverty-CO<sub>2</sub> emission nexus. However, the impact of inclusive finance has not been examined in the previous studies.

Scholars have not reached a unanimous conclusion in the discussion of the relationship between inclusive finance and CO<sub>2</sub> emissions. There are three main viewpoints. The first holds that financial development can promote CO<sub>2</sub> emissions through wealth effect and scale effect. Sadorsky (2010) took 22 emerging market countries as examples and found that financial development stimulated the purchasing of high-energy consumption products such as cars and houses, thus realizing an increase in CO<sub>2</sub> emissions through the wealth effect. The next year, Sadorsky (2011) found that financial development helped accelerate the expansion of enterprise production scale, realizing an increase in CO<sub>2</sub> emissions through the scale effect. Zhang (2011) and Le et al. (2020) further verified the positive correlation between financial development and CO<sub>2</sub> emissions. The second believes that financial development can inhibit CO<sub>2</sub> emissions through structural effect and technical effect. Shahbaz et al. (2013) tested the financial development-CO<sub>2</sub> emissions relationship using Malaysian time-series data and clarified that financial development eased the pressure on CO<sub>2</sub> emissions

through technological innovation. Xiong and Qi (2018) took 30 provinces in China from 1997 to 2011 as a research case; based on STIRPAT and dynamic panel data models, they confirmed that financial development had four effects on CO<sub>2</sub> emissions, among which technical and structural effects were conducive to CO<sub>2</sub> emission reduction. The third focuses on the nonlinear impact of financial development on CO<sub>2</sub> emissions. Nasreen and Anwar (2015) concluded that the relationship between financial development and CO<sub>2</sub> emissions was closely related to the state of national economic development. When economic development was at a low level, financial development would aggravate CO<sub>2</sub> emissions. When economic development was at a higher level, financial development would, on the contrary, inhibit CO<sub>2</sub> emissions. Based on the ARDL method, Abbasi and Riaz (2016) verified that financial variables played a role in mitigating emissions only in more economically developed states, which explained the uncertainty of current study results.

In conclusion, the existing studies attach more importance to the linear relationship between poverty and CO<sub>2</sub> emissions, which may lead to a kind of one-sided understanding of the relationship between poverty and CO<sub>2</sub> emissions. Different from the past works, an ARDL model, a moderating effect model, and a dynamic panel threshold model will be applied to the study of the nonlinear relationship between poverty and CO<sub>2</sub> emissions in this paper at the same time, which provides an innovative tool for future research and clarifies the relationship exploration between poverty and CO<sub>2</sub> emissions more systematic.

## Methodology and data

### Model setting

In order to comprehensively explore the relationship among poverty, inclusive finance, and CO<sub>2</sub> emissions, three models including an ARDL model, a moderating effect model, and a dynamic panel threshold model are constructed in this section. First, we will use the ARDL model to preliminarily determine whether there is an equilibrium relationship among poverty, inclusive finance, and CO<sub>2</sub> emissions. If the model confirmed a long-run dynamic equilibrium nexus among poverty, inclusive finance, and CO<sub>2</sub> emissions, a unified research framework will be used to explore the impact mechanism among them. At present, there is much literature on the impact of inclusive finance on poverty (Li et al. 1998; Beck et al. 2004; Jeanneney and Kpodar 2011; Dhriti 2015; Park and Mercado 2018) and the impact of inclusive finance on CO<sub>2</sub> emissions (Sadorsky 2010; Zhang 2011; Shahbaz et al. 2013; Nasreen and Anwar 2015; Le et al. 2020). Based on these literature works, inclusive finance will

be considered as an influencing factor of the poverty-CO<sub>2</sub> emissions nexus. Therefore, a moderating effect model and a dynamic panel threshold model will be used to explore the impact of inclusive finance on the poverty-CO<sub>2</sub> emissions nexus from the overall and heterogeneous levels.

### Autoregressive distribution lag model

To explore the equilibrium relationship among poverty, inclusive finance, and CO<sub>2</sub> emissions, this study adopts the panel autoregressive distribution lag (ARDL) model. Compared with the traditional cointegration model, the ARDL model has the following advantages. There is a consistent estimate, whether the variable is  $I(0)$  or  $I(1)$ . And, it has sufficient robustness in the case of small samples. Moreover, the ARDL model can also estimate the short-term and long-term relationship of variables through linear change. Using the panel ARDL model, the explained variable  $CE$  (total CO<sub>2</sub> emissions) can be defined as:

$$\ln CE_{it} = u_i + \sum_{j=1}^p \lambda_{ij} \ln CE_{it-j} + \sum_{j=0}^q \delta_{ij} \ln Z_{it-j} + \xi_{it} \quad (1)$$

where  $i$  and  $t$  represent province and time, respectively.  $CE$  is the total CO<sub>2</sub> emissions of each province.  $Z$  denotes poverty and inclusive finance, respectively. In addition,  $u_i$  stands for fixed effects.

The further linear change of the above formula is:

$$\Delta \ln CE_{it} = u_i + \theta_i (\ln CE_{it-1} - \varphi_i \ln Z_{it}) + \sum_{j=1}^{p-1} \lambda_{ij}^* \Delta \ln CE_{it-j} + \sum_{j=0}^{q-1} \delta_{ij}^* \Delta \ln Z_{it-j} + \xi_{it} \quad (2)$$

where  $\varphi_i$  represents the long-term influence coefficient.  $\lambda_{ij}^*$  and  $\delta_{ij}^*$  represent the short-term influence coefficient.  $\theta_i$  represents the error correction term coefficient; if  $\theta_i$  is significantly negative, it proves that there is a cointegration relationship between  $CE_{it}$  and  $Z_{it}$ , and there is a reverse regulation mechanism. This paper uses the mixed group average estimation method (PMG) proposed by Pesaran et al. (1999) and the group average estimation method (MG) proposed by Pesaran and Smith (1995) to estimate the ARDL (1,1,1) model.

### Moderating effect model

To investigate the role of inclusive finance in the relationship between poverty and CO<sub>2</sub> emissions in China at the overall level, this paper adds poverty and the interaction term of inclusive finance and poverty into the classic EKC (Panayotou 1993) model. Besides, considering the role of path dependence, this paper introduces the first-order lag term of the explained variable to construct the following moderating effect model:

$$\begin{aligned} \ln CE_{it} = & \alpha_0 + \alpha_1 \ln CE_{it-1} + \alpha_2 \ln POV_{it} + \alpha_3 \ln IFI_{it} \\ & + \beta_1 \ln EG_{it} + \beta_2 \ln EG_{it}^2 + \delta \ln POV_{it} * IFI_{it} \\ & + \rho \ln X_{it} + u_i + \lambda_t + \xi_{it} \end{aligned} \quad (3)$$

where  $i$  and  $t$  represent province and time, respectively.  $CE$  is the total CO<sub>2</sub> emissions of each province.  $POV$  stands for the poverty level.  $IFI$  measures inclusive finance.  $EG$  and  $EG^2$  are economic growth and its square, respectively.  $X$  denotes other control variables, which include population size, technological level, industrial structure, and financial openness.

### Dynamic panel threshold model

The moderating effect model tests how inclusive finance plays a role in poverty-CO<sub>2</sub> emissions nexus at the overall level. However, there are differences in the financial support of various regions in China, and inclusive finance shows significant heterogeneity. As a result, the impact of inclusive finance on poverty-CO<sub>2</sub> emissions nexus may also show heterogeneous characteristics, which could result in a threshold effect. The threshold effect means that exceeding the threshold will break the original balance, which was first used in the research of consumer psychology and genetics. With the further expansion of the theoretical meaning, more and more scholars used the threshold effect model to solve economic problems. Therefore, this paper should further consider a threshold effect of inclusive finance on poverty-CO<sub>2</sub> emissions nexus at the heterogeneity level.

Previous studies usually used the grouping method to investigate the threshold effect (Wang et al. 2019; Wang and Zhang 2021a, b). However, the grouping value often depends on subjective judgment, which may lead to deviation of the determined threshold value. In contrast, Hansen (1999) proposed the threshold regression model, which was effective for determining the nonlinear threshold value through the automatic identification of sample data. However, the threshold model is only suitable for the non-dynamic panel model because it ignores the processing of endogenous variables. Considering that CO<sub>2</sub> emissions may have a certain dynamic lag, we have to avoid the endogenous problems. To solve these problems, a dynamic threshold panel model is established as follows based on the practice of Kremer et al. (2012) and Wang et al. (2022):

$$\begin{aligned} \ln CE_{it} = & \alpha_0 + \alpha_1 \ln CE_{it-1} + \alpha_2 \ln POV_{it} * I(q_{it} \leq \gamma_1) \\ & + \alpha_3 \ln POV_{it} * I(q_{it} > \gamma_1) + \rho \ln X_{it} + u_i + \lambda_t + \xi_{it} \end{aligned} \quad (4)$$

where  $Y_{it}$  is the explained variable;  $d_{it}$  is the core explanatory variable;  $X_{it}$  is the control variable;  $q_{it}$  is the threshold variable; and  $\gamma$  is the specific threshold value.  $I(\bullet)$  is the indicator function.

### Variable and data description

The sample in this paper includes China's 30 provinces (excluding Tibet, Hong Kong, Macao, and Taiwan due to the availability of data) over the period 2005–2019. The data required in this paper were taken from the 2005 to 2019 *China Statistical Yearbook*, the *China Rural Poverty Monitoring Report*, provincial statistics bureaus, and the national statistical bureau. The variables selected in this paper are as follows:

- (1) Explained variable: CO<sub>2</sub> emissions ( $CE$ ). The two major sources of CO<sub>2</sub> in China are fossil fuel combustion and cement production. If only fuel combustion is considered, CO<sub>2</sub> emissions will be largely underestimated. Therefore, this paper uses the following formula to calculate the total CO<sub>2</sub> emissions of each province.

$$CE = \sum_{j=1}^8 F_j * E_j + VCE * CEDC \quad (5)$$

where  $j$  is the fuel type,  $F_j$  represents the CO<sub>2</sub> emissions coefficient of each fuel; and  $E_j$  denotes the consumption of different fuels.  $VCE$  is the total output of cement.  $CEDC$  is the CO<sub>2</sub> emissions factor of cement production. This paper selects 0.496 as the value of  $CEDC$  based on the Carbon Dioxide Information Analysis Centre (CDIAC).

- (2) Core explanatory variable: poverty ( $POV$ ). In this paper, the poverty incidence rate indicates the regional poverty level. There are multiple single indicators to measure poverty at home and abroad, such as per capita income, per capita growth rate of household final consumption expenditure, and poverty incidence (Dollar and Kraay 2002; Ho and Iyke 2018; Rizk and Slimane 2018). Among them, the poverty incidence rate is the most used indicator to describe the poverty situation in China. Because of the limited official data on this indicator, we used the number of residents with subsistence allowances as the number of the poor to measure the poverty incidence rate based on Huang (2006).
- (3) Regulating variable and threshold variable: inclusive finance ( $IFI$ ). To measure this variable comprehensively, we referred to the practice of Sarma (2008) to measure it from the dimensions of permeability, availability, and utility. The index covers ten indicators simultaneously (see Table 1). To determine the weight of each dimension reasonably, this paper uses the entropy weight method and Euclidean distance method together.

Inclusive finance is constructed through the following three steps.

First, the min–max method is used to normalize the data:

$$z_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{6}$$

where  $x_{ij}$ ,  $x_{\max}$ ,  $x_{\min}$ , and  $z_{ij}$  are the observed value, maximum value, minimum value, and normalized value of the index, respectively.

Second, the entropy weight method is used to calculate the weight,  $w_j$ , of each index. According to the definition of information entropy, the information entropy of a set of data is:

$$e_j = -(\ln n)^{-1} \sum_{i=1}^n p_{ij} \ln p_{ij} \tag{7}$$

$$p_{ij} = \frac{z_{ij}}{\sum_{i=1}^n z_{ij}} \tag{8}$$

$$w_j = \frac{1 - e_j}{\sum_{j=1}^k (1 - e_j)} \tag{9}$$

Third, inclusive finance is constructed by the Euclidean distance method.

$$IFI_{it} = 1 - \sqrt{\frac{w_1^2(1 - z_{1t})^2 + w_2^2(1 - z_{2t})^2 + \dots + w_i^2(1 - z_{it})^2}{w_1^2 + w_2^2 + \dots + w_i^2}} \tag{10}$$

(4) Control variables: Based on existing research (Grossman and Krueger 1992; York et al. 2003; Asongu 2018; Yu and Xu 2019; Le et al. 2020), this article selects population scale, economic growth and its square, technological level, industrial structure, inclusive finance, and financial openness as control variables. The calculation and descriptive statistics for each variable are shown in Table 2.

## Results and discussion

### Results of panel unit root test and cointegration test

To avoid spurious regression, we carried out the ADF, IPS, and LLC tests for each variable. As can be seen from Table 3, all the variables are stable after the first-order difference, thus the validity of the estimation results can be guaranteed.

The unit root test found that poverty, inclusive finance, and CO<sub>2</sub> emissions were unstable, so Pedroni and Westerlund cointegration tests were further used to test the cointegration relationship among variables (Pedroni 1999; Westerlund 2005). As shown in Table 4, the Pedroni cointegration test contains 7 statistics, of which 5 statistics (panel rho, panel PP, panel ADF, group PP, and group ADF) reject the original assumption that there is no cointegration.

**Table 1** Construction of inclusive finance

Dimension	Indicator	Unit	Polarity
Permeability	Number of bank branches per 10,000 square kilometers	bank/10,000 km <sup>2</sup>	Positive
	Number of bank branches per 10,000 people	bank/10,000 person	Positive
	Number of employees per 10,000 square kilometers	person/10,000 km <sup>2</sup>	Positive
	Number of employees per 10,000 people	person/10,000 person	Positive
Availability	Per capita loan	10,000 CNY/person	Positive
	Per capita deposit	10,000 CNY/person	Positive
Utility	The proportion of various loan balances in GDP	%	Positive
	The proportion of various deposit balances in GDP	%	Positive
	Per capita premium income	CNY/person	Positive
	The proportion of premium income in GDP	%	Positive

**Table 2** Variable selection and descriptive statistics

Variable	Calculation	Mean	Std. Dev	Min	Max
CE	$CE = \sum_{j=1}^8 F_j * E_j + VCE * CEDC$	13,659.16	8972.63	555.82	47,669.20
POV	Number of the poor/number of total population	6.81	4.60	0.015	23.53
IFI	–	0.09	0.10	0.01	0.55
POP	–	4479.21	2689.44	543.00	11,521.00
EG	GDP/POP	4.24	2.69	0.54	16.42
EGs	–	25.22	35.09	0.29	269.76
T	Energy consumption/GDP	111.55	78.23	11.38	495.25
IS	Industrial added value/GDP	45.23	8.44	16.16	59.05
FO	FDI/GDP	33.05	25.64	0.16	127.79

**Table 3** Results of panel unit root test

	Variable	ADF	IPS	LLC	Conclusion
I (0)	<i>lnCE</i>	0.0000***	0.4632	0.0198**	Non-stationary
	<i>lnPOP</i>	0.9995	1.0000	0.0000***	Non-stationary
	<i>lnEG</i>	0.0000***	0.9563	0.0368**	Non-stationary
	<i>lnEGs</i>	1.0000	1.0000	0.0000***	Non-stationary
	<i>lnPOV</i>	0.0000***	0.8408	0.0000***	Non-stationary
	<i>lnIFI</i>	0.0816*	0.0008***	0.0000***	Stationary
	<i>lnT</i>	0.1612	0.8552	0.0002***	Non-stationary
	<i>lnIS</i>	0.0000	0.9555	0.3563	Non-stationary
	<i>lnFO</i>	0.3876	0.5392	0.0795*	Non-stationary
I (1)	<i>lnCE</i>	0.0036***	0.0000***	0.0000***	Stationary
	<i>lnPOP</i>	0.0025***	0.0000***	0.0000***	Stationary
	<i>lnEG</i>	0.0000***	0.0000***	0.0000***	Stationary
	<i>lnEGs</i>	0.0010***	0.0001***	0.0000***	Stationary
	<i>lnPOV</i>	0.0000***	0.0000***	0.0000***	Stationary
	<i>lnIFI</i>	0.0000***	0.0000***	0.0000***	Stationary
	<i>lnT</i>	0.0005***	0.0000***	0.0000***	Stationary
	<i>lnIS</i>	0.0003***	0.0000***	0.0000***	Stationary
	<i>lnFO</i>	0.0000***	0.0000***	0.0000***	Stationary

\*\*\*, \*\*, and \* respectively mean significant at the level of 1%, 5%, and 10%

Westerlund cointegration tests also rejected the original hypothesis at the level of 10%. Therefore, there is a long-term relationship between poverty, inclusive finance, and CO<sub>2</sub> emissions.

### Regression of ARDL model

Table 5 shows the short-term and long-term estimation results of MG and PMG. The results of Hausman test show

**Table 4** Results of cointegration test

Method	Statistics	
Pedroni test	Panel v-statistic	1.043
	Panel rho-statistic	-2.518**
	Panel PP-statistic	-13.84***
	Panel ADF-statistic	-14.52***
	Panel rho-statistic	-0.3259
	Panel PP-statistic	-14.89***
Westerlund test	Panel ADF-statistic	-15.69***
	Variance ratio	-1.5249*

This table displays the results of residual-based panel cointegration tests developed by Pedroni (1999). Under the null hypothesis of lack of cointegration, all test statistics are normalized to be distributed under  $N(0,1)$ . Lag orders are determined using HQIC

\*\*\*, \*\*, and \* respectively mean significant at the level of 1%, 5%, and 10%

that the original hypothesis cannot be rejected, and the PMG estimation result is more robust. According to the PMG estimation results, A 1% increase in poverty can decline CO<sub>2</sub> emissions by 0.3456% in the short term. In other words, although poverty hinders economic growth, impoverished people exert little pressure on the environment. It seems that the linkage among poverty, economic growth, and the environment is irreconcilable. On the other hand, poverty increased by 1%, and CO<sub>2</sub> emissions increased by 0.0628% in the long run. That is, poverty alleviation tends to reduce CO<sub>2</sub> emissions, which supports the evidence for the win–win relationship. But it is only a long-term dynamic trend, the underlying mechanisms of which need to be further explored. At the same time, we note that the coefficient of inclusive finance is still negative regardless of the time. It suggests that the process of inclusive finance is likely to reduce CO<sub>2</sub> emissions. The finding is justifiable because funds from finance development can promote innovation in cleaner production technologies.

The error correction term coefficient is significantly negative at the level of 1% and the coefficient value is -0.6684. This result illustrates that there is a long-term and stable equilibrium relationship among poverty, inclusive finance, and CO<sub>2</sub> emissions. It means that poverty alleviation, inclusive financial development, and environmental protection could co-exist in the long term. The finding coincides with the fact that in well-developed economies with low carbon, the financial sector is booming. Therefore, we should integrate the three variables into a unified research framework. Based on this consideration, we will further analyze the role of inclusive finance in the nonlinear relationship between poverty and CO<sub>2</sub> emissions from the overall level and heterogeneity level through a moderating effect model and a dynamic panel threshold model.

**Table 5** Short-run and long-run results of PMG

Dependent variables	MG	PMG
Long-run relationship		
<i>lnPOV</i>	0.8089 (1.45)	0.0628*** (3.97)
<i>lnIFI</i>	-1.2964 (-1.53)	-0.4431*** (-13.63)
Short-run relationship		
Error correction	-0.7219*** (-10.26)	-0.6684*** (-11.91)
$\Delta \ln POV$	-0.2093** (-2.44)	-0.3456*** (-4.26)
$\Delta \ln IFI$	0.0203 (0.23)	-0.0040 (-0.04)
<i>C</i>	4.0938*** (7.23)	4.2306*** (11.69)
<i>H</i> -test <i>p</i> value	0.9164	

\*\*\*, and \*\* respectively mean significant at the level of 1%, 5%, and 10%

### Regression of moderating effect model

By introducing an interaction term between inclusive finance and poverty, the poverty-CO<sub>2</sub> emissions relationship affected by inclusive finance is tested at the overall level. The estimated results are shown in Table 6. From the overall level, poverty exerts a significantly negative effect on carbon emissions in China. The finding is consistent with the report from Uitto (2016). In this sense, it is noteworthy that poverty alleviation in China may lead to environmental degradation. According to the EKC hypothesis, environmental pollution increases as per capita income rises at a low-income level. However, the regression coefficient of the interaction term is 0.0185, which is significantly positive at the 1% level. We can deduce that inclusive finance has a significant moderating effect on the relationship between poverty and CO<sub>2</sub> emissions. More specifically, the CO<sub>2</sub> emission reduction effect of poverty gradually decreases with the development of inclusive finance. A plausible mechanism is that inclusive finance can directly reduce CO<sub>2</sub> emissions, which offsets the negative effect of poverty on CO<sub>2</sub> emissions. The finding is supported by Shahbaz et al. (2013), which clarified that finance development performed well in inhibiting CO<sub>2</sub> emissions through technical effect. Simultaneously, the results are not in line with those reported by Zhang (2011).

**Table 6** Regression results of the moderating effect model

Variable	Coefficient	Std. Dev	Sig
<i>lnCE<sub>t-1</sub></i>	0.3015	0.0375	0.000
<i>lnPOV</i>	-0.0168	0.0027	0.000
<i>lnIFI</i>	-0.0718	0.0093	0.000
<i>lnPOV*lnIFI</i>	0.0185	0.0046	0.000
<i>lnPOP</i>	0.6551	0.0267	0.000
<i>lnEG</i>	0.7866	0.0469	0.000
<i>lnEGs</i>	-0.0556	0.0130	0.000
<i>lnT</i>	0.6009	0.0155	0.000
<i>lnIS</i>	0.1327	0.0229	0.000
<i>lnFO</i>	-0.0235	0.0051	0.000
<i>sargan</i>			1.0000
<i>AR (2)</i>			0.4084

**Table 7** Threshold effect test

Null hypothesis		Critical value					
		F	<i>p</i>	BS	1%	5%	10%
<i>IFI</i>	No threshold	25.09	0.0567	300	34.5383	25.9274	22.3671
	Single threshold	4.37	0.9233	300	36.7206	22.6362	19.0577

### Regression of dynamic panel threshold model

At the heterogeneity level, a dynamic panel threshold model is applied. According to the model setting in the “Model setting” section, this paper adopted STATA14.0 for analysis. First, this paper tested formula (4) under the null hypothesis of no threshold and single threshold. The *F* and *p* values tested under various hypotheses are shown in Table 7. It can be seen from the test results that the self-sampling *p* values corresponding to the two hypothesis tests are 0.0567 and 0.9233, respectively, which means that we can reject the null hypothesis without threshold at the significance level of 10%, but we cannot reject the null hypothesis of the single threshold. Therefore, this article should choose the single panel threshold model. The threshold estimates and corresponding confidence intervals are listed in Table 8. The threshold value is the value when LR is equal to 0; the confidence interval is the interval formed by all LR below the critical value  $\gamma$  at the 95% significance level. Based on the obtained threshold value of -1.3107 (*IFI*=0.2696), we can divide the development of inclusive finance into the low level (*IFI* ≤ 0.2696) and high level (*IFI* > 0.2696).

Table 9 shows the results of the dynamic threshold regression estimation with inclusive finance as the threshold variable. As the result shows, the effect of poverty on CO<sub>2</sub> emissions is not monotonously increasing or decreasing at various stages of inclusive finance but shows obvious threshold characteristics. According to the second column of Table 9, the elastic coefficients corresponding to poverty are -0.0217 and 0.0695 at each stage of inclusive finance. The economic implication is that when inclusive finance is at a low level (*IFI* ≤ 0.2696), each 1% increase in poverty will curb about 0.0217% of CO<sub>2</sub> emissions, and vice versa (*IFI* > 0.2696), it will lead to an increase of about 0.0695% of CO<sub>2</sub> emissions. These findings confirm the “Poverty-CO<sub>2</sub> Paradox” occurred in China at the first stage and was broken in the second stage.

**Table 8** Threshold estimates and confidence intervals

	Estimation	Lower limit	Higher limit
Threshold	-1.3107 ( <i>IFI</i> =0.2696)	-1.3529	-1.2742

95% confidence interval was obtained by bootstrap method at 300 iterations



**Table 9** Results of dynamic panel threshold model

Variable	Coefficient	Std. Dev	Sig
$\ln CE_{t-1}$	0.3062	0.0404	0.000
$\ln POV1$ ( $\ln IFI \leq -1.3107$ )	-0.0217	0.0039	0.000
$\ln POV2$ ( $\ln IFI > -1.3107$ )	0.0695	0.0124	0.000
$\ln IFI$	-0.0929	0.0119	0.000
$\ln POP$	0.6775	0.0849	0.000
$\ln EG$	0.7700	0.0610	0.000
$\ln EGs$	-0.0546	0.0152	0.000
$\ln T$	0.5942	0.0125	0.000
$\ln IS$	0.1285	0.0247	0.000
$\ln FO$	-0.0256	0.0040	0.000
<i>sargan</i>			1.0000
<i>AR</i> (2)			0.3374

When inclusive finance is at a low level ( $IFI \leq 0.2696$ ), the improvement of the poverty incidence rate can reduce CO<sub>2</sub> emissions. The finding is justifiable due to the fund restrictions in the fields of consumption and production. As for consumption, the poor often manage the environment in an unsustainable way after receiving funds according to Murad and Nik (2010). The lack of funds from inclusive finance can downsize economic scale and reduce energy consumption. Poverty can thus limit the negative impact of the poor on the environment. For instance, the poor cannot afford large energy-consuming commodities such as family cars and houses. In the aspect of production, the poor tend to engage in agricultural production with lower CO<sub>2</sub> emissions. Poverty also inhibits the input of production. As a result, environmental degradation and CO<sub>2</sub> emissions are greatly minimized. Based on this analysis, the low level of inclusive finance reduces the chance of access to funds for the poor, thus poverty reduction is not conducive to improving the environment.

When inclusive finance has reached a higher stage ( $IFI > 0.2696$ ), the improvement of the poverty incidence rate has a detrimental effect on the quality of environment. In terms of the traditional view, to improve their income, the poor usually deplete the fossil fuels irrationally, which emits large amounts of pollutants in the atmosphere. The empirical finding is in line with Khalid (2019) and Ramphal (1992). In other words, poverty alleviation reduces CO<sub>2</sub> emissions with a high level of inclusive finance. Another reasonable analysis is as follows from the perspective of financial inclusion. Firstly, the development of inclusive finance can improve the employment rate of the financial service industry in poor areas and reduce the employment rate of primary and secondary industries, thereby reducing CO<sub>2</sub> emissions, which is consistent with Jin et al. (2020). Secondly, inclusive finance eases the credit constraints for low- and middle-income groups. This can not only reduce

poverty but also upgrade the industrial structure, which can further reduce CO<sub>2</sub> emissions. Finally, inclusive finance will provide savings and insurance services to the poor. China is a large country of savings. Poverty reduction may not lead to a significant increase in consumption but will increase savings, which can reduce CO<sub>2</sub> emissions to a certain extent (Lin et al. 2020). Therefore, the “Poverty-CO<sub>2</sub> Paradox” in China can be broken through inclusive finance.

In terms of specific regions, by 2019, only four provinces had crossed the threshold value of inclusive finance, namely, Beijing, Tianjin, Shanghai, and Jiangsu. They crossed the threshold for the first time in 2006, 2018, 2005, and 2005. It has been acknowledged that the residents with subsistence allowances living in these provinces have higher income levels than other provinces. Based on the EKC theory, environmental pollution decreases as per capita income rises at high-income levels. This suggests that the development of inclusive finance and income are important factors in alleviating relative poverty and CO<sub>2</sub> emissions. Besides, most provinces are in the stage of low inclusive finance. This means that most provinces exist the “Poverty-CO<sub>2</sub> Paradox.” Currently, the impact of poverty on CO<sub>2</sub> emissions is negative. This conclusion is also supported by Khan’s research on ASEAN countries (Khan 2019).

From the regression results of the control variables, the coefficient of  $\ln POP$  is significantly positive at 1%, which means that the expansion of population size strengthens the increment of CO<sub>2</sub> emissions. This result is similar to the findings of Yu et al. (2018). The coefficient of  $\ln EG$  is significantly positive, while that of  $\ln EGs$  is negative. Because the technological proxy index in this paper is the energy consumption per unit of output, the proxy index is complementary to the technological level. The estimated coefficient of  $\ln T$  is 0.5942, which indicates that the decline of low carbon technology level will lead to the increment of CO<sub>2</sub> emissions. Based on this, we believe that technological upgrades would inhibit CO<sub>2</sub> emissions. The  $\ln IS$  coefficient is significantly positive, which denotes that an increase in the proportion of secondary industry would aggravate CO<sub>2</sub> emissions. The coefficient of  $\ln FO$  is negative, which implies that current financial openness is a powerful tool to reduce CO<sub>2</sub> emissions.

## Conclusions and policy recommendations

This paper investigates the linkage among China’s poverty, inclusive finance, and CO<sub>2</sub> emissions to achieve the goal of “No Poverty” and “Climate Action.” Based on the panel data of 30 provinces in China from 2005 to 2019, an ARDL model, a moderating effect model, and a dynamic panel threshold model were constructed. The major findings are as follows: (1) a long-term stable equilibrium relationship

among poverty, inclusive finance, and CO<sub>2</sub> emissions was confirmed. (2) On the whole, inclusive finance is a factor affecting the poverty-CO<sub>2</sub> emissions nexus. The negative effect of poverty on CO<sub>2</sub> emissions diminishes with the moderation of inclusive finance. (3) From the perspective of heterogeneity, poverty alleviation will lead to an increase of CO<sub>2</sub> emissions when inclusive finance is at a low level ( $IFI \leq 0.2696$ ), and conversely, it reduces CO<sub>2</sub> emissions.

Our findings support that China could achieve goal towards “No Poverty” and “Climate Action” simultaneously in the long run in the following ways:

- 1) Develop inclusive finance vigorously, and promote all regions to reach the threshold level.

The results shown in Table 6 indicate that poverty will gradually play a less important role in reducing CO<sub>2</sub> emissions with the adjustment of inclusive finance. Furthermore, emission reduction may turn into emissions increment when *IFI* has crossed its threshold. Combined with the estimated threshold in Table 9, poverty alleviation could bring about CO<sub>2</sub> emission reduction when the development of inclusive finance is at a high level ( $IFI > 0.2696$ ). Combined with our calculation results, the development level of inclusive finance has crossed the threshold in only four provinces, namely, Beijing, Tianjin, Shanghai, and Jiangsu, which means most provinces are in the stage of low inclusive finance. Inclusive finance is difficult to break the “Poverty-CO<sub>2</sub> Paradox” at this stage. Consequently, each province should develop inclusive finance vigorously and push regional inclusive finance to reach the threshold level ( $IFI > 0.2696$ ).

- 2) Raise the threshold of subsistence allowances, and promote in-depth poverty reduction.

The coefficient of  $\ln POV2$  is 0.0695, which indicates that when the development of inclusive finance is at a high level ( $IFI > 0.2696$ ), every 1% increase in poverty will lead to an increase of about 0.0695% of CO<sub>2</sub> emissions. That is, we can take action to achieve “No Poverty” and “Climate Action” at the same time. In this paper, the poverty proxy index is the proportion of the population at minimum living security in each province. This means poverty reduction should increase the standard of minimum living security and reduce the proportion of the population living at that level. To make full use of poverty reduction in promoting CO<sub>2</sub> emission reduction in the post-COVID-19 era, China should improve the threshold of subsistence allowances and reduce the proportion of people living under subsistence allowances.

- 3) Attach importance to technology and financial openness in carbon emission reduction, and promote the transformation of the green economy from the source.

According to Table 9, the elasticity coefficient of  $\ln T$  is 0.5942, which occupies the first rank among major factors reducing CO<sub>2</sub> emissions. So technological progress is the most powerful tool for promoting CO<sub>2</sub> emission reduction, and full attention should thus be paid to its application in CO<sub>2</sub> emission reduction. Considering the source of technological progress, financial openness occupies a prominent position in the innovation of low-carbon environmental technologies. Thereafter, enterprises should attach great importance to the CO<sub>2</sub> emission reduction effect of technology and financial openness, and seize the opportunity of the green economy transformation after the epidemic to accelerate China’s progress towards carbon peak and carbon neutrality.

This study was systematically conducted with China as the research object, which contributes the most to global poverty reduction and accounts for the largest proportion of global CO<sub>2</sub> emissions. However, in order to improve the applicability of our research model and findings, further researchers can select panel data from other countries or global panel data as the research object for expanding and deepening this research.

**Author contribution** Yang Yu: conceptualization, visualization, writing—reviewing and editing, formal analysis, supervision, investigation, visualization, project administration, funding acquisition.

Qi Liu: methodology, software, data curation, formal analysis, validation, investigation, writing—original draft preparation.

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