The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: a double-edged sword

Article

Accepted Version

Wang, M. ORCID: https://orcid.org/0000-0002-5378-0798, Liu, J. ORCID: https://orcid.org/0000-0002-2128-6015, Rahman, S. ORCID: https://orcid.org/0000-0002-0391-6191, Sun, X. and Sriboonchitta, S. (2023) The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: a double-edged sword. Economic Analysis and Policy, 77. pp. 792-808. ISSN 2204-2296 doi: https://doi.org/10.1016/j.eap.2022.12.030 Available at https://centaur.reading.ac.uk/109701/

To link to this article DOI: http://dx.doi.org/10.1016/j.eap.2022.12.030

Publisher: Elsevier

Journal Pre-proof

The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: A double-edged sword

Mengjiao Wang, Jianxu Liu, Sanzidur Rahman, Xiaoqi Sun, Songsak Sriboonchitta

PII: S0313-5926(22)00238-7
DOI: https://doi.org/10.1016/j.eap.2022.12.030
Reference: EAP 894

To appear in: *Economic Analysis and Policy*

Received date : 25 July 2022
Revised date : 10 December 2022
Accepted date : 29 December 2022

Please cite this article as: M. Wang, J. Liu, S. Rahman et al., The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: A double-edged sword. *Economic Analysis and Policy* (2023), doi: https://doi.org/10.1016/j.eap.2022.12.030.

The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: A double-edged sword

Mengjiao Wang[a], Jianxu Liu[b,d,*], Sanzidur Rahman[b,c], Xiaoqi Sun[a], Songsak Sriboonchitta[d]

[a] Center of Data Economics & Network Study, ICOI, Shenzhen University, Shenzhen 518060, China

[b] Faculty of Economics, Shandong University of Finance and Economics, Jinan 250000, China

[c] School of Agriculture, Policy and Development, University of Reading, Whiteknights, Reading, RG6 6EU, UK

[d] Faculty of Economics, Chiang Mai University, Chiang Mai 50200, Thailand

[*]**Corresponding author:** Jianxu Liu, Associate Professor, Faculty of Economics, Shandong University of Finance and Economics, Jinan, Shandong, China. Contact email: 20180881@sdufe.edu.cn (J. Liu).

Email address of all authors:

mjwang@szu.edu.cn (M. Wang);
20180881@sdufe.edu.cn (J. Liu);
srahman@plymouth.ac.uk (S. Rahman);
sunxiaoqi@szu.edu.cn (X. Sun)
songsakecon@gmail.com (S. Sriboonchitta)

Declaration of competing interests

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

Acknowledgements

This research is supported by a general project from Humanities and Social Science Foundation of the Ministry of Education of China (Grant No. 22YJC790129) and project from National Natural Science Foundation of China (Grant No. 71863022).

The effect of China's outward foreign direct investment on carbon intensity of Belt and Road Initiative countries: A double-edged sword

Abstract. The objective of this study is to identify the double-edged sword effect of China's outward foreign direct investment (OFDI) on carbon intensity of Belt and Road Initiative (BRI) countries. To this end, a two-tier stochastic frontier model is employed to estimate the two-sided effects of China's OFDI simultaneously based on a sample of 56 BRI countries covering the period from 2005 to 2018. The empirical results show that China's OFDI has both promotion effect and reduction effect on carbon intensity of BRI countries and the BRI region on average is left with a net reduction effect of approximately -3.0%. Such net effect of China's OFDI on carbon intensity varies over time and across countries. Furthermore, the net effect of China's OFDI varies with different levels of economic development, energy consumption, industrialization, and urbanization of individual BRI countries. Policy implications are provided for both China and BRI countries to promote sustainable cooperation and accelerate low-carbon development in BRI region.

Keywords: Double-edged sword; China's OFDI; Carbon intensity; Belt and Road Initiative; Two-tier stochastic frontier model

1. Introduction

The Belt and Road Initiative (BRI), first proposed by Chinese President Xi Jinping in 2013, is a transcontinental and inclusive cooperation network with objectives to strengthen trading system and achieve collaborative development among participating countries (Hussain et al., 2020). By 2020, BRI has expanded to 139 countries[1] worldwide, covering approximately 39% of global gross domestic product (GDP) and over 60% of the world population (Yang et al., 2022). The initiative has actively improved trade, foreign investment and infrastructure in participating countries, giving a strong boost to economic growth in BRI region (Foo et al., 2020; Ma, 2022). If fully implemented, BRI is expected to increase trade by 1.7 to 6.2 percent for the world and increase global real income by 0.7 to 2.9 percent (World Bank, 2019).

However, with such rapid development of BRI region comes significant environmental challenges. Many BRI countries have become the fastest growing emerging economies with huge energy consumption. The production and investment activities in BRI region based on fossil energy consumption could create huge carbon

[1] The Belt and Road Initiative is an open and inclusive concept with no clearly defined spatial boundaries.

footprints which may go against with the aims of Paris Agreement to avoid climate change and limit global warming to 2℃ above pre-industrial level (Jiang et al., 2021; Wu et al., 2021; Sun and Shi, 2021). Based on the World Bank statistical data (World bank, 2022), from 2013 to 2018, the average annual growth rate of carbon emissions of BRI countries[2] is 2.84%, which is much higher than the world's average annual growth rate of 0.81%. By 2018, the overall carbon emissions of BRI countries have accounted for over 30% of the global emissions. With the industrialization, urbanization and opening process moving on, the BRI region could be one of the largest sources of growing carbon emissions in the coming decades, thereby calling for prompt transition to a low-carbon development path.

The environmental sustainability issues of BRI region also bring escalating pressure for future economic cooperation under BRI. Foreign direct investment (FDI) is one of the major types of BRI cooperation which plays a crucial role in boosting local economic growth of BRI countries (Su et al., 2022; Ma, 2022). The outward foreign direct investment (OFDI) from China to BRI countries has increased dramatically since the initiative was launched. There is evidence that BRI on average has promoted 36% more China's OFDI to BRI countries than to non-BRI countries (Yu et al., 2019). Nevertheless, as the investment from China to BRI region is mainly concentrated in energy intensive sectors, such as, manufacturing, infrastructure and construction, production and supply of electricity, the environmental consequences of China's OFDI continue to cause controversy (Yu et al., 2019; Liu et al., 2020). As the world's largest emitter of carbon dioxide, China has pledged 60-65% cut in carbon intensity by 2030. There are concerns whether BRI is a platform for China to pursue its green growth strategy by relocating domestic pollution-intensive industries to BRI countries (Jiang et al., 2019; Cai et al., 2018; Mahadevan and Sun, 2020). As the initiator of BRI, it is necessary for China to promote green investment in BRI region in order to align the BRI cooperation with global carbon reduction goals and jointly build a green Belt and Road with BRI countries.

A clear assessment on the carbon impact of China's OFDI in BRI countries is of great reference value for policy makers to promote green investment and accelerate low-carbon development in BRI region. Insufficient studies have been conducted to investigate the impact of China's OFDI on carbon emissions of BRI countries, however, conclusions are inconsistent. Some studies have indicated that China's OFDI overall

[2] The statistics is based on 65 countries (include China) which has been identified to participate in BRI by 2015.

tends to reduce carbon emissions of BRI countries (Wu et al., 2021; Zhuang et al., 2021; Li et al., 2021; Su et al., 2022). By contrast, Muhammad et al. (2020) and Wang et al. (2021) suggested that China could export carbon emissions to BRI countries via OFDI, and the effect of China's OFDI on carbon emissions is different depending on the development levels of host countries.

The above inconsistent conclusions provide necessity for further analysis on the carbon impact of China's OFDI in BRI region from at least two perspectives. Firstly, it is widely believed that FDI could have two-sided effects (i.e., promotion effect and reduction effect) on carbon emissions, which would act as a double-edged sword for low-carbon development of host countries (Neves et al., 2020; Song et al., 2021). The net effect of the two opposing forces could be positive, negative or negligible depending on which effect dominates the other. Existing findings of most studies were based on common panel data models which could only reflect the overall impact of FDI on carbon emissions (Muhammad et al., 2020; Muhammad and Long, 2021; Dong et al., 2022). How to quantify the promotion, reduction, and net effects of China's OFDI on carbon emissions of BRI countries is challenging, requiring an appropriate methodology. Secondly, As BRI involves a wide range of countries with various development characteristics, the different influence of China's OFDI on carbon emissions of host countries with heterogeneous characteristics worth further investigation.

In the light of above background, this study investigates the impact of China's OFDI on carbon intensity (carbon emissions per unit of GDP) of 56 BRI countries over the period 2005-2018. We assume that China's OFDI have a double-edged sword effect on carbon intensity of BRI countries. On the one hand, China's OFDI to pollution-intensive industries may result in huge energy consumption and carbon emissions, producing a "promotion effect" on carbon intensity. On the other hand, a "reduction effect" could occur because the productivity and technology spillovers from China's OFDI could contribute to the technical progress and economic growth of BRI countries, thereby reducing carbon intensity. A two-tier stochastic frontier model is applied to estimate the promotion, reduction, and net effects of China's OFDI. Further, the different effects of China's OFDI over different sample periods and across countries with various development characteristics are compared, thereby providing reference for policy making to promote investment cooperation in a more sustainable direction under BRI.

The rest of the study is organized as follows: Section 2 reviews basic theories and related literatures. Section 3 presents the analytical framework, empirical model and describes the data. Empirical results are discussed in Section 4. Finally, Section 5 provides conclusions and draws policy implications.

2. Literature review

2.1 Theoretical background

The pollution haven hypothesis (Walter and Ugelow, 1979) and pollution halo hypothesis (Zarsky, 1999) are two basic theories explaining the double-edged sword effect of FDI on environmental quality. The haven theory holds that FDI could lead to an increase in environmental pollution of host countries. Confronting urgent demand of economic development and fierce competition in the global market, developing countries may attract FDI with lax environmental standards or weak environmental protocols, thus encouraging developed countries to transfer pollution-intensive industries to developing countries (Waheed et al., 2019; Hao et al., 2021). Conversely, FDI could have beneficial impacts on the ecological environment of host countries, which is supported by the pollution halo hypothesis. By applying universal environmental standards, multinational enterprises engaging in FDI will tend to spread green technology to local firms in host countries, thus contributing to the improvement of energy efficiency and environmental quality (Pao and Tsai, 2011).

The two opposing hypotheses have been argued in a myriad of studies and produced conflicting results upon empirical applications. Until now, some studies provided evidence in support of the pollution haven hypothesis (Eskeland and Harrison, 2003; Cole, 2004; Nepal et al., 2021), whilst other studies drew conclusions in accordance with the pollution halo hypothesis (Zhang and Zhou, 2016; Neves et al., 2020; Wu et al., 2020; Acheampong et al., 2019). Another view, based on the Environment Kuznets Curve (EKC) hypothesis, illustrates that since FDI will promote economic development, there is also an inverted U-shaped relationship between FDI and environmental pollution. In the short term, FDI will increase environmental pollution, while in the long term, FDI will reduce the pollution (Malik et al., 2020; Hao et al., 2020). Until now, little consensus has been achieved in a clear effect direction of FDI on environmental quality. The inconsistent conclusions on the environmental effects of FDI can be tracked back to its different impact mechanisms. Most researchers have posited that FDI could affect ecological environment indirectly by changing the economic scale, industrial structure and technical innovation of host countries, which are referred to as the scale effect, composition effect (structure effect) and technique effect, respectively (Grossman and Krueger, 1995; Hao et al., 2021).

The scale effect of FDI indicates that economic growth contributed by FDI will lead to higher levels of energy consumption and carbon emissions, which corresponds to the pollution haven hypothesis (Antweiler et al., 2001). Generally speaking, majority of literature agreed that the scale effect of FDI exerts a negative impact on the environmental quality of host countries (Dinda, 2004; Hao et al., 2020). With regard to carbon intensity, the direction of scale effect depends on the relative effect sizes of FDI on carbon emissions and on economic growth of host countries. The carbon intensity of a country will increase if FDI contributes to carbon emissions more than economic growth and vice versa.

The composition effect indicates that FDI can affect environmental quality by changing industrial structure of the host countries (Liobikiene and Butkus, 2019). A positive composition effect on the environment arises when FDI promotes the transformation of industrial structure in host countries from resource-intensive or pollution-intensive industries to low-polluting industries. On the contrary, the transfer of pollution-heavy industries from developed countries to developing countries via FDI will negatively affect local environment (Yang et al., 2021). Therefore, the composition effect is attributed to both the halo and haven hypothesis.

The technique effect is supported by the pollution halo theory. FDI from developed countries can directly provide green and advanced technologies to local enterprises, which helps to improve production and energy efficiency, thereby contributing to the low-carbon development of host countries (Hao et al., 2020; Buhar et al., 2020). The technology spillovers from multinational enterprises to local enterprises can be achieved via different indirect channels, such as decomposition effect, competition effect, labor turnover effect and industrial linkages (Hao et al., 2021; Liu et al., 2021).

Therefore, the double-edged sword effect of FDI on carbon intensity of host countries may co-exist through different paths of scale, composition, and technique effects. Based on the above theories, the effect mechanism of FDI on carbon intensity of host countries is presented in Fig.1.

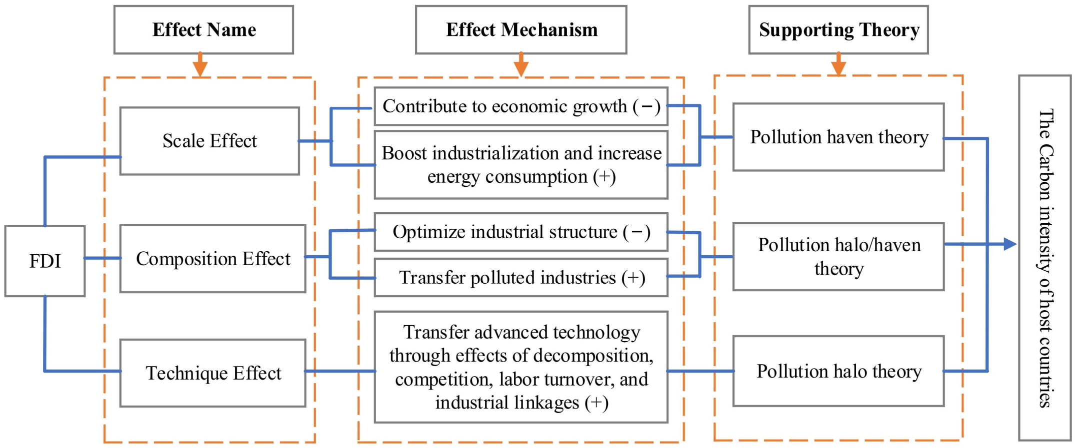


Fig.1. The effect mechanism of FDI on carbon intensity of host countries (+ and − indicate the effect directions of FDI on carbon intensity).

2.2 The major influencing factors of carbon emissions in BRI countries

Given the essential role of the BRI region in tackling global climate change, the low-carbon development of BRI countries has attracted global attention. Considerable research has been conducted to explore factors affecting carbon emissions of BRI countries.

First, the carbon emissions of BRI countries are closely related with their economic development level. Majority of the BRI region has achieved rapid economic growth with increasing carbon emissions. In particular, the investment-driven emissions obviously increased (Fan et al., 2019; Wu et al., 2021). Furthermore, it is widely believed that there is an inverse U-shape relationship between economic development and carbon emissions (Ahmad et al., 2020; Muhammad and Long, 2021).

Second, a positive relationship between energy consumption and carbon emissions of BRI region has been identified (Fan et al., 2019; Rauf et al., 2020; Muhammad and Long, 2021; Shi et al., 2022), whereas renewable energy consumption is conductive to reduce carbon emissions and improve environmental quality of BRI countries (Rauf et al., 2020; Anwar et al., 2021). Similarly, it is widely recognized that the industrialization process is positively correlated with carbon emissions of BRI countries. The production activities of energy-intensive industries, such as, mining, manufacturing and construction are primary sources of carbon emissions (Hussain et al., 2020, Wu et al., 2021, Su et al., 2022).

Next, it is clear that globalization and international economic cooperation could significantly affect carbon emissions in the BRI region. International trade and investment are making the world economy and environment become an interwoven network. A country's carbon emissions are also deeply influenced by other countries' production demands and activities (Jiang et al., 2019). In terms of trade cooperation, Ahmad et al. (2020) suggested that trade openness is positively related with the environmental quality of BRI countries. Specifically, Muhammad and Long (2021) and Sun et al. (2019) indicated that the effect of trade on carbon emissions varies with the income level of BRI countries. As another major form of international cooperation, FDI has been found to have a heterogeneous effect on carbon emissions of BRI region. Muhammad et al. (2020) concluded that FDI increases carbon emissions in BRI countries and supports "pollution haven" hypothesis, while different conclusions were drawn by Ahmad et al. (2020) and Wu et al. (2021), which indicated that FDI can improve environmental quality of host countries.

In addition, the levels of urbanization, political and institutional factors (e.g., political stability, corruption control, raw of law), and financial development also have been identified as important driving forces of carbon emissions in BRI region with various conclusions (Ahmad et al., 2020; Rauf et al., 2020; Muhammad and Long, 2021, Su et al., 2022). The detailed information of recent literature that examined the influencing factors of carbon emissions in BRI countries is summarized in Table 1.

Previous literature has provided valuable theoretical foundations and empirical findings on the relationship between FDI and carbon emissions. Since BRI was launched, a number of studies have paid attention to major influencing factors (including China's OFDI) of carbon emissions in BRI region. Although the existing literature covers a similar scope with this study, we contribute to the ongoing research in two aspects. First, a two-tier stochastic frontier model is applied to identify the magnitudes of promotion, reduction and net effects of China's OFDI on carbon intensity of major BRI countries. The double-edged sword effect of China's OFDI thus will be clearly presented. Second, the changes in the effect of China's OFDI on carbon intensity before and after the BRI was launched are compared, thereby capturing the changing role of China's OFDI in the low-carbon development of BRI countries given the potential influence of the BRI. Third, we compare differential effects of China's OFDI in countries with various levels of economic development, energy consumption, industrialization, urbanization and degree of openness, thereby revealing different patterns of the influence of China's OFDI on carbon intensity of BRI countries characterized with different development characteristics.

Table 1. Literature on the influencing factors of carbon emissions in BRI countries

Reference	Sample	Period	Methods	Explained variables	Influencing factors
Fan et al. (2019)	46 BRI countries	2000-2014	PDA model	TCE	ED, EC
Wu et al. (2021)	63 BRI countries	2002-2017	Panel model	CEGDP	ED, EC, IND, FDI, TO, UR
Ahmad et al. (2020)	90 BRI countries	1990-2017	Pooled OLS	TCE	ED, EC, FD, FDI, TO, UR
Muhammad and Long (2021)	65 BRI countries	2000-2016	IV-GMM	TCE	IF, FDI, TO, PS, CR, LR
Rauf et al. (2020)	65 BRI countries	1981-2016	Dynamic Panel model	CEPC	EC, FD, REC
Muhammad et al. (2020)	65 BRI countries	2000-2016	2SLS	TCE	UR, FDI, IM, EX
Shi et al. (2022)	33 BRI countries	2005–2016	Panel model	CEGDP	ED, EC, FDI
Anwar et al. (2020)	33 BRI countries	1986-2018	IV-GMM	CEPC	REC, EC, TO
Hussain et al. (2020)	56 BRI countries	1990-2014	VECM	CEPC	ED, EC, IND UR, TO
Sun et al. (2019)	49 BRI countries	1991-2014	VECM	CEPC	TO, ED, EC
Su et al. (2022)	67 BRI countries	2003-2017	Panel quantile model	TCE	ED, EC, IND, UR
Lee et al. (2022)	48 BRI countries	1984-2017	panel quantile model		ED, EC, FDI, TRADE, PS

Note: (1) Methods: PDA (production-theoretical decomposition analysis); OLS (ordinary least squares); IV-GMM (instrumental variable-generalized method of moments); VECM (vector error correction model); 2SLS (two-stage least squares); DDF (directional distance function); (2) Explained variables: TCE (total carbon emissions); CEGDP (carbon emissions per unit of GDP); CEPC (carbon emissions per capita); (3) Influencing factors: ED (economic development); EC (energy consumption); IND (Industrialization); FDI (foreign direct investment); TO (trade openness); UR (urbanization); IF (institutional factors); FD (financial development); REC (renewable energy consumption); IM (import); EX (export); PS (political stability); CR (corruption control); LR (rule of law).

3. Empirical model and data

3.1 Analytical framework

Based on related literature, we establish an analytical framework to illustrate the two-sided effects of China's OFDI on carbon intensity of a host country, which will be linked to a two-tier stochastic frontier model in the following subsection. The carbon intensity of a country can be expressed as

$$CI = \underline{CI} + \eta(\overline{CI} - \underline{CI}) \quad (1)$$

where CI is the actual level of carbon intensity in the country. The values of CI may range from the lower bound $\underline{CI}$ to the upper bound $\overline{CI}$ depending on the influence of China's OFDI. FDI from China could have two opposing effects on carbon intensity of host countries, i.e., the promotion effect and the reduction effect. The parameter $\eta(0 \leq \eta \leq 1)$ is an unobservable coefficient which measures the relative power of the two opposing effects of China's OFDI in affecting carbon intensity. When $\eta = 1$, $CI = \overline{CI}$, indicating that the country's carbon intensity will reach its upper bound when China's OFDI only has a promotion effect, but without reduction effect. On the contrary, when $\eta = 0$, $CI = \underline{CI}$, indicating that the lower bound of carbon intensity will be reached when China's OFDI only has a reduction effect, but no promotion effect.

To clarify the promotion effect and reduction effect of China's OFDI on carbon intensity more clearly, we can rewrite Eq. (1) as

$$CI = \mu(x) + \eta\left(\overline{CI} - \mu(x)\right) - (1-\eta)\left(\mu(x) - \underline{CI}\right) \tag{2}$$

where $\mu(x)$ represents the baseline level of carbon intensity given country-specific development characteristics without taking account of the impact of China's OFDI. The promotion effect (PE) of China's OFDI on carbon intensity can be written as

$$PE = \eta\left(\overline{CI} - \mu(x)\right) \tag{3}$$

Also, the reduction effect (RE) of China's OFDI can be indicated by

$$RE = (1-\eta)\left(\mu(x) - \underline{CI}\right) \tag{4}$$

As a result, the net effect (NE) of China's OFDI can be calculated as the difference between PE and RE, i.e.,

$$NE = PE - RE = \eta\left(\overline{CI} - \mu(x)\right) - (1-\eta)\left(\mu(x) - \underline{CI}\right) \tag{5}$$

The values of NE can be positive or negative depending on the relative power between PE and RE.

3.2 Linking the analytical framework to a two-tier stochastic frontier model

To estimate the effect of China's OFDI on carbon intensity of BRI countries, we follow Kumbhakar and Parmeter (2009) and Liu et al. (2019) to link Eq. (2) to a two-tier stochastic frontier model as follows:

$$CI_{it} = x'_{it}\beta + \varepsilon_{it} = x'_{it}\beta + w_{it} - u_{it} + v_{it} \tag{6}$$

where CI_{it} is the actual carbon intensity level of country i at time t. x'_{it} is a set of influencing variables of carbon intensity that reflect the country-specific characteristics, such as levels of economic development, energy consumption, industrialization, and urbanization, β is the parameter vector. The composite error ε_{it} in two-tier stochastic frontier model is divided into three error components w_{it}, u_{it}, and v_{it}. The error components $w_{it} = \eta(\overline{CI} - \mu(x)) \geq 0$ and $u_{it} = (1-\eta)(\mu(x) - \underline{CI}) \geq 0$ capture the promotion effect (Eq. (3)) and reduction effect (Eq. (4)) of China's OFDI on carbon intensity, respectively. Both w_{it} and u_{it} are assumed to be independent and identically distributed (*i.i.d.*) variables with exponential distribution, which can be expressed as $w_{it} \sim i.i.d. Exp\ (\sigma_w)$ and $u_{it} \sim i.i.d. Exp\ (\sigma_u)$, respectively. The error component v_{it} is the random disturbance term which is normally distributed as $v_{it} \sim i.i.d. N\ (0,\ \sigma_v^2\ )$.

Based on the above settings, the conditional expectations of w_{it} and u_{it} can be derived as

$$E(w_{it}|\varepsilon_{it}) = \frac{1}{\lambda} + \frac{\sigma_v[\phi(-h_{it}) + h_{it}\Phi(h_{it})]}{\Phi(h_{it}) + exp(a_{it} - b_{it})\,\Phi(c_{it})} \qquad (7)$$

and

$$E(u_{it}|\varepsilon_{it}) = \frac{1}{\lambda} + \frac{exp(a_{it} - b_{it})\,\sigma_v[\phi(-c_{it}) + c_{it}\Phi(c_{it})]}{\Phi(h_{it}) + exp(a_{it} - b_{it})\,\Phi(c_{it})} \qquad (8)$$

where $\lambda = \frac{1}{\sigma_u} + \frac{1}{\sigma_w}$, $a_{it} = \frac{\sigma_v^2}{2\sigma_u^2} + \frac{\varepsilon_{it}}{\sigma_u}$, $b_{it} = \frac{\sigma_v^2}{2\sigma_w^2} - \frac{\varepsilon_{it}}{\sigma_w}$, $c_{it} = -\frac{\varepsilon_{it}}{\sigma_v} - \frac{\sigma_v}{\sigma_u}$, and $h_{it} = \frac{\varepsilon_{it}}{\sigma_v} - \frac{\sigma_v}{\sigma_w}$. $\Phi(\cdot)$ and $\phi(\cdot)$ represent the cumulative distribution function (CDF) and the probability density function (PDF) of standard normal distribution, respectively. The detailed derivation process can be referred to Kumbhakar and Parmeter (2009).

Since the dependent variable is in logarithmic form, we can use Eqs. (9) and (10) to get an exact percentage measure of the increase or decrease in carbon intensity due to the promotion effect or reduction effect of China's OFDI as follows:

$$E(1 - e^{-w_{it}}|\varepsilon_{it}) = 1 - \frac{\lambda}{1+\lambda}\frac{[\Phi(c_{it}) + exp(b_{it} - a_{it})exp\ (\sigma_v^2/2 - \sigma_v h_{it})\Phi(h_{it} - \sigma_v)]}{exp\ ((b_{it} - a_{it}))[\Phi(h_{it}) + exp(a_{it} - b_{it})\,\Phi(c_{it})]} \qquad (9)$$

$$E(1 - e^{-u_{it}}|\varepsilon_{it}) = 1 - \frac{\lambda}{1+\lambda}\frac{[\Phi(h_{it}) + exp(a_{it} - b_{it})exp\ (\sigma_v^2/2 - \sigma_v c_{it})\Phi(c_{it} - \sigma_v)]}{\Phi(h_{it}) + exp(a_{it} - b_{it})\,\Phi(c_{it})} \qquad (10)$$

Then, the net effect (NE_{it}) of China's OFDI can be calculated according to

$$NE_{it} = PE_{it} - RE_{it} = E(1 - e^{-w_{it}}|\varepsilon_{it}) - E(1 - e^{-u_{it}}|\varepsilon_{it}) \qquad (11)$$

A positive value of net effect occurs when the promotion effect of China's OFDI is greater than the reduction effect, implying that FDI from China in general can increase the carbon intensity of BRI countries. On the contrary, a negative value of net effect implies that the reduction effect of China's OFDI plays a dominant role, thereby contributing to a net reduction in carbon intensity of BRI countries.

Following Parmeter (2018) and Liu (2019), we can add covariates to explain both one-sided error terms w_{it} and u_{it}. As w_{it} and u_{it} are exponentially distributed, we have

$$E(w_{it}|\boldsymbol{x}, z_w, z_u) = \sigma_w exp\,(z'_{w,it}\delta_w) \tag{12}$$

and

$$E(u_{it}|\boldsymbol{x}, z_w, z_u) = \sigma_u\, exp(z'_{u,it}\delta_u) \tag{13}$$

where z_w and z_u are the covariates that affect w_{it} and u_{it}, δ_w and δ_u are estimated parameters of z_w and z_u, respectively. The parameters σ_w and σ_u are to set the scale of each individual mean and are not dependent upon z_w and z_u. To investigate the two-sided effects of China's OFDI on carbon intensity of BRI countries, China's OFDI stock in BRI countries will be used as z_w and z_u to explain both one-sided error terms w_{it} and u_{it}. Based on the estimations of Eqs. (12) and (13), we can further extract the share of changes in $E(w_{it})$ and $E(u_{it})$ due to the influence of China's OFDI by multiplying an adjustment coefficient of $(1 - \sigma_w/E(w_{it}))$ and $(1 - \sigma_u/E(u_{it}))$, respectively.

3.3 The data and variables

Based on the availability of data, we construct a panel dataset of 56 BRI countries from 2005 to 2018 to investigate the double-edged sword effect of China's OFDI on carbon intensity of sample countries. The 56 countries are major destinations of Chinese investment in BRI region. According to *the Statistical Bulletin of China's Outward Foreign Direct Investment*, China's OFDI stock in the 56 countries has reached more than US\$200.0 billion by the end of 2020, accounting for over 99% of China's OFDI stock in total 63 BRI countries that have been counted. We use carbon intensity as the carbon emission performance indicator, which is measured as carbon dioxide emissions per unit of GDP. A country is considered to achieve a low-carbon development mode when its carbon intensity decreases with economic growth (Yang et al., 2021; Shi et al., 2022). Instead of using data of FDI inflow, the FDI stock of China in BRI countries is applied as the representative variable of China's OFDI for the following reasons. First, FDI stocks are the accumulation of flows, therefore can capture long-run effects more efficiently; Second, the data of FDI flow from China to some BRI countries include zero and negative values because of no-investment or disinvestment in some special years, hence the log model is not proper for FDI flow data (Zhuang et al., 2021; Muhammad et al., 2020; Yu et al., 2021).

Based on literature review, we select several control variables reflecting country-specific characteristics which has been identified to have significant influence on carbon emissions of BRI region. These are economic development (Ehigiamusoe et al., 2020; Muhammad et al., 2020), energy consumption (Waheed et al., 2019; Muhammad and Long, 2021), industrialization (Hussain et al., 2020; Su et al., 2022), urbanization (Yu and Xu, 2019; Wu et al., 2021; Hussain et al., 2020), trade openness (Acheampong et al., 2019; Nguyen et al., 2021), and political stability (Muhammad and Long, 2021; Lee et al., 2022). We use GDP per capita to represent economic development level, the primary energy consumption per capita as a proxy for energy consumption, industry value added share of GDP to represent industrialization process, and the proportion of urban population to total population as a proxy for urbanization. Moreover, trade openness is used as the representative variable of opening degree, which are proxied by the ratio of total imports and exports of goods and services to GDP. The political stability index from the World Governance Indicators (WGI) of the World Bank is selected to reflect the stability in political and governance issues of BRI countries. The detailed definitions of variables and data sources are provided in Table 2, and the descriptive statistics of variables are presented in Table 3.

Table 2. Definitions and sources of variables

Variables	Definitions	Sources
Carbon Intensity (lnCI)	The logarithm of carbon dioxide emissions per GDP (kg per 10,000 USD)	WDI
COFDI (lnCOFDI)	The logarithm of the stock of China's OFDI in BRI countries (USD)	Statistical Bulletin of China's OFDI
GDP per capita (lnGDPPC)	The logarithm of GDP per capita (USD)	WDI
Energy Consumption (lnEC)	The logarithm of energy consumption per capita (kg of oil equivalent)	WDI
Industrialization (IND)	Industry value added (% of GDP)	WDI
Urbanization (URB)	Urban population (% of total population)	WDI
Trade Openness (TRADE)	Trade (% of GDP)	WDI
Political stability (PSI)	Political stability index (-2.5 weak; 2.5 strong)	WGI

Note: Monetary values are based on 2010 constant prices; OFDI: outward foreign direct investment; WDI: World Development Indicators (https://data.worldbank.org); Statistical Bulletin of China's OFDI (http://hzs.mofcom.gov.cn/); WGI: Worldwide Governance Indicators (https://databank.worldbank.org/source/worldwide-governance-indicators).

Table 3. Descriptive statistics of variables

Variables	Mean	SD	Min	Max	Observations
lnCI	8.77	0.61	7.26	10.51	784
lnCOFDI	18.32	2.64	11.55	24.53	784
lnGDPPC	8.67	1.21	6.22	11.15	784
lnEC	7.44	1.03	4.75	9.87	784
IND	33.73	14.61	13.10	119.0	784
URB	58.68	21.37	15.15	100.0	784
TRADE	99.10	53.50	0.17	437.3	784
PSI	-0.30	0.97	-3.01	1.62	784

Note: SD: standard deviation.

The BRI countries are spread across different continents and have various socio-economic characteristics. To reduce heterogeneity among sample countries, we control different groups of countries according to different geographic regions and development levels (Adeel-Farooq et al., 2021). Based on the World Bank Country Classification of countries by region and income level of 2018[3], we construct four groups of countries by region, i.e., East Asia & Pacific, Europe & Central Asia, Middle East & North Africa, and South Asia, and other four groups of countries by income levels, which are high-income, upper-middle-income, lower-middle-income, and low-income groups.

4. Results and discussion

4.1 Estimation results of two-tier stochastic frontier models

The estimation results of carbon intensity regression for sample BRI countries are displayed in Table 4. Models (1) and (2) are the baseline regressions using ordinary least squares (OLS) method and two-way fixed effect (FE) model, respectively. The two-tier stochastic frontier models are applied in models (3)-(6) to investigate the double-edged sword effect of China's OFDI on carbon intensity of BRI countries. The estimates of two-tier stochastic frontier model without considering any covariate of w_{it} and u_{it} are presented in model (3). In model (4), China's OFDI is introduced as the covariate of w_{it} to estimate its promotion effect on carbon intensity of BRI countries. Meanwhile, we use China's OFDI as covariate to explain u_{it} in model (5), thereby examining its reduction effect on carbon intensity. Further, China's OFDI is taken as

[3] Historical classifications of countries by region and income level can be found from World Bank at https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups.

the covariates of both error terms w_{it} and u_{it} in model (6) to explore its two-sided effects at the same time.

Table 4. Estimation results of two-tier stochastic frontier models

	(1) OLS	(2) FE	(3) 2TSF	(4) 2TSF-ucov	(5) 2TSF-wcov	(6) 2TSF-uwcov
lnGDPPC	-0.769***	-0.865***	-0.946***	-0.940***	-0.929***	-0.932***
	(0.033)	(0.041)	(0.030)	(0.020)	(0.0001)	(0.000)
lnEC	0.925***	1.136***	1.025***	1.024***	0.981***	0.986***
	(0.031)	(0.040)	(0.026)	(0.022)	(0.0001)	(0.000)
IND	0.002**	0.002**	-0.002***	-0.002***	-0.001***	-0.001***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.000)	(0.000)
URB	0.003***	0.014***	0.002	0.001***	0.001***	0.001***
	(0.001)	(0.003)	(0.001)	(0.0001)	(0.0002)	(0.000)
TRADE	-0.0001	0.0002	-0.001***	-0.001***	-0.001***	-0.001***
	(0.0003)	(0.0003)	(0.0002)	(0.0001)	(0.00)	(0.000)
PSI	0.017	0.050***	0.052***	0.048***	0.018***	0.020***
	(0.017)	(0.015)	(0.015)	(0.006)	(0.001)	(0.000)
lnCOFDI	0.002	-0.003				
	(0.004)	(0.004)				
Promotion Effect						
lnCOFDI(Z_w)					0.019***	0.158***
					(0.001)	(0.001)
σ_w			0.049	0.068***	0.108***	0.114***
			(0.049)	(0.006)	(0.003)	(0.003)
Reduction Effect						
lnCOFDI(Z_u)				0.018*		0.020***
				(0.009)		(0.001)
σ_u			0.249***	0.176***	0.234***	0.160***
			(0.014)	(0.026)	(0.010)	(0.004)
σ_v			0.129***	0.122***	0.000	0.000
			(0.020)	(0.008)	(0.001)	(0.0002)
Constant term	7.762***	6.925***	9.412***	9.350***	9.371***	9.362***
	(0.259)	(0.295)	(0.234)	(0.082)	(0.666)	(0.724)
Country Dummy by region	YES	—	YES	YES	YES	YES
Country Dummy by income level	YES	—	YES	YES	YES	YES
Year Dummy	YES	—	YES	YES	YES	YES
Observations	784	784	784	784	784	784
R-squared	0.778	0.589				
Log-likelihood			-45.97	-44.92	-38.61	-37.51
AIC			149.9	149.8	137.2	137.0

Note: Significance at 0.01, 0.05, and 0.10 levels indicated by ***, **, *; Standard errors in parentheses; OLS: ordinary least squares; FE: fixed effect; 2TSF: two-tier stochastic frontier model; 2TSF-ucov: 2TSF with the covariate of u_{it}; 2TSF-wcov: 2TSF with the covariate of w_{it}; 2TSF-uwcov: 2TSF with covariates of both u_{it} and w_{it}; AIC: Akaike information criterion.

The smallest Akaike information criterion (AIC) value of model (6) indicates that it provides the best fitting estimations among models (3)-(6). Moreover, the coefficients of $\ln COFDI(Z_w)$ and $\ln COFDI(Z_u)$ in model (6) are both significant, indicating the existence of both the promotion and reduction effects of China's OFDI. In addition, the signs and significance for the coefficients of most variables in model (6) are consistent with the estimations by OLS and FE method in models (1) and (2), which further validates credibility of model (6). Hence, the analysis below will be based on the estimates of model (6) only.

First of all, the significant negative coefficient of GDP per capita (lnGDPPC) indicates that with the development of the economy, carbon intensity of BRI countries tends to decrease during the sample period. Secondly, the coefficients of energy consumption (lnEC) and urbanization (URB) are both positive and statistically significant, implying that carbon intensity of BRI countries tends to increase with the increase of energy use and the process of urbanization. Besides, the industrialization (IND) and trade openness (Trade) are both negatively related with carbon intensity of BRI countries, whereas political stability (PSI) is positively associated with carbon intensity of sample countries.

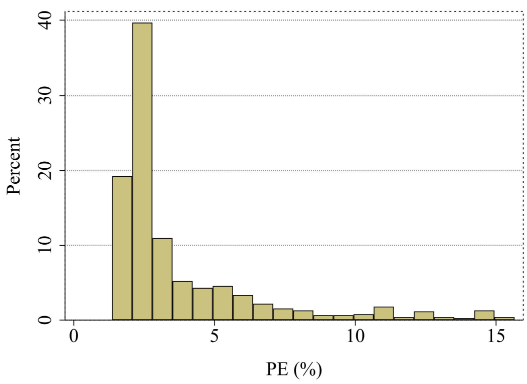
Based on the estimates of model (6), the promotion effect and the reduction effect of China's OFDI in percentage measure can be decomposed based on Eqs. (9) and (10), and the net effect, which is measured by the difference between the promotion effect and the reduction effect, could be calculated. Table 5 displays the statistics of promotion effect, reduction effect, and net effect of China's OFDI on carbon intensity of BRI countries. On average, the promotion effect of China's OFDI could increase carbon intensity of BRI countries by 3.76%, while the reduction effect decreases carbon intensity by 6.76%. Consequently, the net effect of China's OFDI on average contribute to a decrease of carbon intensity in BRI countries by 3.0% compared with the baseline level. At different quantile levels, however, the net effect of China's OFDI tells different stories. The net effect for the first quantile (Q1) is -5.34%, which means that FDI from China could contribute to reduce carbon intensity of BRI countries by at least 5.34% for 25% observations of the sample. While at the median level (Q2), the promotion effect starts catching up with the reduction effect, leaving a net effect of -1.56% on carbon intensity. By contrast, China's OFDI shows a net promotion effect in the third quantile (Q3), leading to an increase in carbon intensity by 1.30% above the baseline level.

Table 5. The effects of China's OFDI on carbon intensity of BRI countries in percentage measure

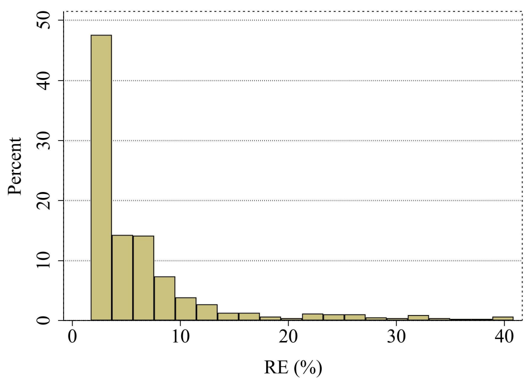
Variables	Symbols	Mean (%)	SD (%)	Q1(%)	Q2(%)	Q3(%)
Promotion Effect	$E(1-e^{-w}\|\varepsilon)$	3.76	2.79	2.19	2.59	4.21
Reduction Effect	$E(1-e^{-u}\|\varepsilon)$	6.76	6.88	2.99	3.95	7.38
Net Effect	$E(e^{-u}-e^{-w}\|\varepsilon)$	-3.00	8.08	-5.34	-1.56	1.30

Note: SD: standard deviation; Q1, Q2, Q3 are quantiles that divide data into four equally sized groups.

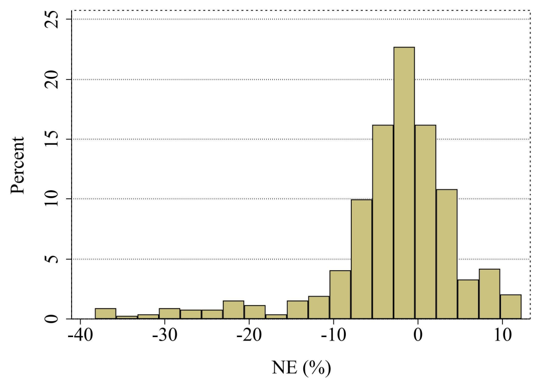
To reveal the effects of China's OFDI in a more intuitively way, the frequency distributions of the promotion, reduction, and net effects are presented in Fig.2 (a)-(c), respectively. As shown in Fig.2 (a) and (b), the distributions of promotion effect and reduction effect are both asymmetric. The promotion effect of China's OFDI is below 10% and the reduction effect is below 20% for over 90% of observations, while extreme large values appear only in a few cases. The large values indicate that FDI from China may deeply affect the low-carbon development of relevant host countries in either negative or positive directions. In comparison, the tail of the distribution of promotion effect is heavier than that of reduction effect. As a result, a slight right-skewed distribution of the net effect could be noticed in Fig.2 (c). Nevertheless, the values of net effect are centered around zero with most observations fall into the interval from -10% to 10%. This indicates that FDI from China in general has limited impacts on carbon intensity of sample countries after the neutralization of the two opposing effects.



(a). The promotion effect (PE) of China's OFDI



(b). The reduction effect (RE) of China's OFDI



(c). The net effect (NE) of China's OFDI

Fig.2. Histogram distributions of the promotion effect (PE), reduction effect (RE), and net effect (NE) of China's OFDI.

4.2 Further discussion

4.2.1 The effect of China's OFDI over time

The promotion effect, reduction effect, and net effect of China's OFDI on carbon intensity of BRI countries over years are presented in Fig.3. During 2005 to 2018, the net effect of China's OFDI on average could change the carbon intensity of sample countries by a range of -3.8% to -2.1%. The net effects are less than zero for all years, which is owing to the fact that the reduction effect have an advantage over the promotion effect every year. It is worth noting that from 2014 to 2017, the promotion effect of China's OFDI increases slightly but the reduction effect shows downward trend, yielding a decreasing degree in the net reduction on carbon intensity by China's OFDI. A possible explanation for this might be that soon after the BRI was launched in 2013, China's investment to the BRI countries had been growing rapidly encouraged by the initiative. Compared with pursuing economic benefit, Chinese overseas enterprises and local government may attach less importance to local environmental protection in the early stage. This result also accords with the finding from Wang et al. (2021), which suggests that China's investment could increase carbon emissions of BRI region at the early stage of the BRI.

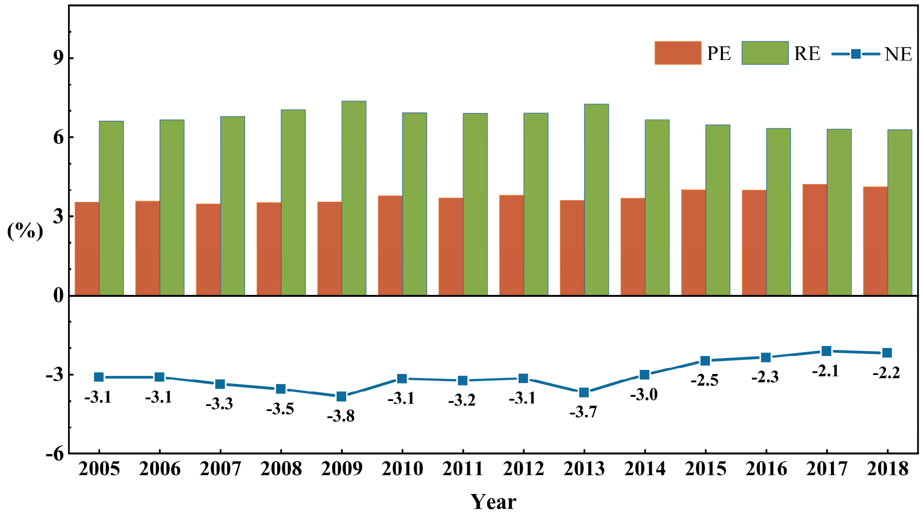


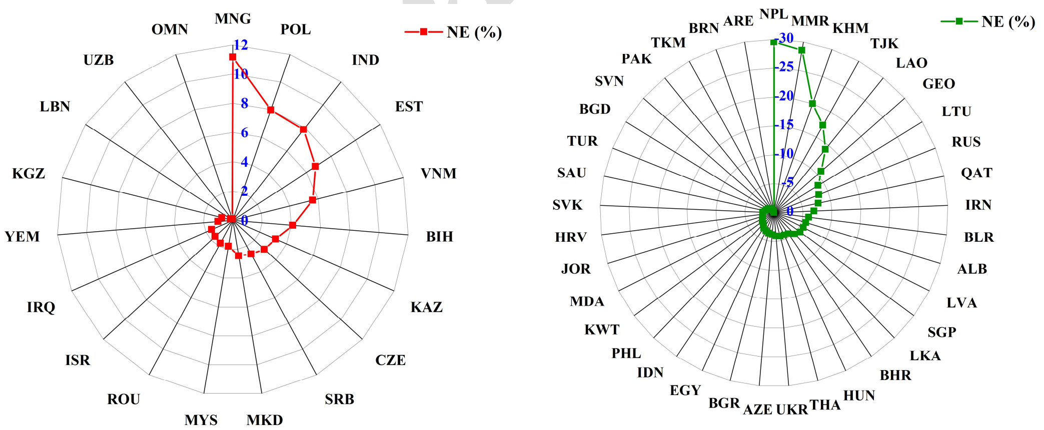
Fig.3. The promotion effect (PE), reduction effect (RE) and net effect (NE) of China's OFDI on carbon intensity of BRI countries over years

To accelerate green development and sustainable cooperation, the Ministry of Ecology and Environment of China released the *Guidance on Promoting Green Belt and Road* in the early of 2017. The guidance aims to spur enterprises to observe relevant environmental protection laws, regulations and standards, and boost green technology and industry development in BRI region. Following this guidance, China has also built a network of technology sharing and cooperation with BRI countries, including a batch of joint research centers (Li et al., 2021). Hence, it is not surprising to observe a downward trend in the net effect of China's OFDI with a decreased promotion effect after 2017. Furthermore, the decreased net effect of China's OFDI could be also attributed to the increasing environmental consciousness of BRI countries.

4.2.2 The effect of China's OFDI at country-specific level

The net effect of China's OFDI on carbon intensity of BRI region at country-specific level is plotted in Fig. 4. The BRI countries, identified by their country code (see Table A1 in Appendix), are arranged in a descending order according to the absolute values of net effect. As shown in Fig. 4 (a), we can observe positive values of net effect in 19 among 56 sample countries from the annual average, indicating that the promotion effect of China's OFDI is greater than the reduction effect in 19 countries. The net effect of China's OFDI could lead to an increase of carbon intensity in these countries ranging from 0.12-11.2%. The net effect is over 5% in five countries, i.e., Mongolia, Poland, India, Estonia, and Vietnam, implying that there is considerable potential for these countries to reduce carbon intensity through scientific utilization of foreign investment from China. On the contrary, as we can see in Fig. 4 (b), there are 37 countries with negative signs of the net effect, implying that the reduction effect of China's OFDI plays a more dominant role in affecting carbon intensity. The carbon intensity of the 37 countries on average can be reduced by 0.02% to 29.6% from the net impact of China's OFDI. The net effect in five countries is less than -10%, namely Nepal, Myanmar, Cambodia, Tajikistan, and Laos, indicating that FDI from China could significantly contribute to the reduction of carbon intensity in these countries. Nevertheless, the net effect in 11 BRI countries is between -2% to 0, meaning that the contribution of China's OFDI on promoting low-carbon development in these countries are still limited.

It is worth noting that Southeast Asian countries are the major destinations of FDI from China. The negative signs of net effect indicate that China's OFDI could contribute to reducing carbon intensity in a majority of Southeast Asian countries, such as Myanmar (-28.56%), Cambodia (-20.02%), Laos (-14.10%), Singapore (-5.60%), and Thailand (-4.21%). In contrast, China's OFDI on average could lead to an increase of carbon intensity in Vietnam and Malaysia by 5.63% and 1.80%, respectively. The different influence of China's OFDI on countries in the same region might be attributed to the heterogeneous characteristics of host countries, such as the differences in economic development, energy consumption, industrialization, and urbanization etc. Hence, the differential impact of China's OFDI on carbon intensity regarding to different development characteristics of host countries is worthy of further exploration.



(a). Countries with a positive sign of net effect (b). Countries with a negative sign of net effect

Fig.4. The net effect (NE) of China's OFDI on carbon intensity of 56 BRI countries at country-specific level.

We further divide the full sample into pre-BRI period (2005-2013) and post-BRI period (2014-2018) to compare differences in two-sided effects of China's OFDI before and after the BRI was launched. The effects of China's OFDI over different sample periods in 19 BRI countries with a net promotion effect (positive value of net effect) are summarized in Table 6, in which ΔNE measures the difference between the net effects of China's OFDI before and after the BRI was launched. It can be seen that the net promotion effect of China's OFDI on carbon intensity has increased in 6 out of 19 countries in post-BRI period compared to pre-BRI period. The largest increase in the net effect (ΔNE=4.66%) has been in Vietnam due to an obvious increase of the promotion effect. Vietnam is becoming a global manufacturing hub and an increasingly attractive destination for foreign investors from China and the whole world. Since the BRI commenced in 2013, the stock of China's FDI in Vietnam has continuously increased with an average annual growth rate of 31.8% from 2013 to 2018. The foreign investment from China to Vietnam has been mainly concentrated in the electric-power and manufacturing industries, which may result in larger carbon emissions with increasing investment. Strategies to achieve low carbon transformation are urgently needed for countries like Vietnam which are in the process of industrialization. In contrast, the net effect of China's OFDI in other 13 countries has decreased in the post-BRI period, implying that the negative influence of China's OFDI on low-carbon development of BRI countries has been reduced in these countries after the BRI was launched.

Besides, the two-sided effects of China's OFDI in the 37 countries with a net reduction effect (negative value of net effect) over different periods, are compared in Table 7. The net effect of China's OFDI in 17 out of 37 countries has increased in the post-BRI period, implying that the net reduction in carbon intensity due to the influence of China's OFDI has decreased in these countries, especially for Laos, Myanmar, and Tajikistan, with a change in the net effect (ΔNE) of 25.80%, 13.07%, and 10.15%, respectively. In particular, owing to a large decrease in the reduction effect and a certain increase in the promotion effect, the net effect of China's OFDI in Laos has increased from -23.32% in pre-BRI period to 2.49% in post-BRI period. It can be concluded that the overall impact of China's OFDI on the carbon intensity of Laos has shifted from a net reduction to a net promotion after the BRI was launched, thereby alerting both China and Laos to take efforts to promote investment cooperation in a sustainable direction. By contrast, we have witnessed a decrease in the net effect of China's OFDI in 20 out of 37 countries, such as Singapore, Thailand, and Iran, with a ΔNE of -8.69%, -3.66%, and -3.15%, respectively. This indicates that the contribution of Chinese investment on reducing carbon intensity of these countries has kept increasing, which provide good models for China and BRI partner countries for further fruitful and sustainable cooperation.

Table 6. The effect of China's OFDI over different sample periods: 19 countries with a positive value of net effect.

Country	Pre-BRI period (2005-2013)			Post-BRI period (2014-2018)			ΔNE (%)
	PE (%)	RE (%)	NE (%)	PE (%)	RE (%)	NE (%)	
MNG	14.52	3.29	**11.24**	14.48	3.41	**11.07**	**-0.17**
POL	10.99	2.87	**8.12**	10.78	3.07	**7.72**	**-0.40**
IND	10.10	3.01	**7.08**	12.71	3.44	**9.27**	**2.18**
EST	10.02	2.25	**7.77**	7.22	2.33	**4.88**	**-2.89**
VNM	7.16	3.21	**3.96**	12.06	3.44	**8.62**	**4.66**
BIH	7.15	2.33	**4.82**	5.39	2.57	**2.82**	**-2.00**
KAZ	6.51	3.34	**3.17**	6.93	3.73	**3.20**	**0.04**
CZE	5.97	2.67	**3.30**	5.22	2.97	**2.24**	**-1.06**
SRB	4.93	2.29	**2.63**	5.37	2.78	**2.59**	**-0.04**
MKD	4.81	1.85	**2.95**	3.84	2.26	**1.59**	**-1.37**
MYS	5.22	3.13	**2.08**	4.76	3.47	**1.29**	**-0.79**
ROU	5.00	2.85	**2.15**	4.08	3.01	**1.07**	**-1.08**
ISR	4.63	2.52	**2.10**	4.05	3.27	**0.77**	**-1.33**
IRQ	4.73	2.95	**1.78**	4.35	3.16	**1.20**	**-0.58**
YEM	3.50	3.13	**0.38**	5.17	3.04	**2.14**	**1.76**
KGZ	3.55	3.48	**0.07**	5.22	3.20	**2.03**	**1.96**
LBN	2.51	2.07	**0.44**	1.98	2.24	**-0.26**	**-0.70**
UZB	3.70	3.11	**0.59**	2.60	3.28	**-0.69**	**-1.28**
OMN	2.51	3.13	**-0.62**	4.35	2.90	**1.45**	**2.06**

PE: promotion effect; RE: reduction effect; NE: net effect; ΔNE is the difference between the NEs of post-BRI period and pre-BRI period; The sample countries are arranged in a descending order according to the values of net effect of the full sample.

Table 7. The effect of China's OFDI over different sample periods: 37 countries with a negative value of net effect.

Country	Pre-BRI period (2005-2013)			Post-BRI period (2014-2018)			ΔNE (%)
	PE (%)	RE (%)	NE (%)	PE (%)	RE (%)	NE (%)	
NPL	2.04	34.72	-32.68	2.38	26.39	-24.01	8.67
MMR	2.61	35.84	-33.23	2.84	23.00	-20.16	13.07
KHM	2.58	24.93	-22.35	2.86	18.69	-15.82	6.53
TJK	2.40	23.33	-20.94	2.62	13.41	-10.78	10.15
LAO	2.54	25.86	-23.32	8.85	6.36	2.49	25.80
GEO	2.29	14.06	-11.77	2.53	11.76	-9.23	2.54
LTU	1.88	10.79	-8.91	2.01	11.03	-9.03	-0.12
RUS	2.79	10.17	-7.38	2.96	13.07	-10.10	-2.72
QAT	2.19	9.21	-7.02	2.58	11.90	-9.32	-2.30
IRN	2.51	8.29	-5.78	2.69	11.62	-8.93	-3.15
BLR	1.86	7.87	-6.00	2.28	8.39	-6.11	-0.11
ALB	1.75	8.04	-6.29	1.91	6.72	-4.81	1.48
LVA	1.62	6.90	-5.29	1.69	8.02	-6.33	-1.05
SGP	2.85	5.34	-2.49	3.21	14.39	-11.19	-8.69
LKA	2.20	9.26	-7.06	2.82	4.54	-1.71	5.35
BHR	1.68	6.45	-4.78	2.07	5.76	-3.70	1.08
HUN	2.35	5.54	-3.19	2.49	8.66	-6.17	-2.98
THA	2.60	5.50	-2.90	2.86	9.43	-6.57	-3.66
UKR	2.08	6.55	-4.47	2.13	5.49	-3.36	1.11
AZE	2.51	6.01	-3.51	2.09	6.48	-4.39	-0.88
BGR	2.04	5.00	-2.96	2.39	7.24	-4.85	-1.89
EGY	2.43	5.93	-3.50	2.52	5.71	-3.20	0.30
IDN	2.67	6.92	-4.25	3.27	4.41	-1.14	3.12
PHL	2.37	6.06	-3.70	3.04	3.72	-0.68	3.02
KWT	1.99	4.92	-2.93	2.59	4.25	-1.66	1.27
MDA	1.69	2.86	-1.17	1.78	5.85	-4.08	-2.90
JOR	2.06	3.59	-1.53	2.30	5.08	-2.78	-1.24
HRV	2.01	3.39	-1.38	2.08	5.10	-3.02	-1.64
SVK	1.91	3.42	-1.51	2.31	5.01	-2.70	-1.19
SAU	2.59	4.13	-1.54	2.78	4.33	-1.55	-0.01
TUR	2.34	3.63	-1.29	2.63	4.12	-1.49	-0.20
BGD	2.35	4.85	-2.50	4.26	2.96	1.30	3.80
SVN	1.90	2.40	-0.50	2.03	4.17	-2.14	-1.64
PAK	2.70	4.21	-1.51	3.92	3.56	0.36	1.86
TKM	2.43	2.82	-0.40	2.58	3.53	-0.95	-0.55
BRN	3.32	3.14	0.18	2.82	3.99	-1.16	-1.34
ARE	2.70	3.43	-0.73	4.94	3.70	1.24	1.96

PE: promotion effect; RE: reduction effect; NE: net effect; ΔNE is the difference between the NEs of post-BRI period and pre-BRI period; The sample countries are arranged in a descending order according to the absolute values of net effect of the full sample.

4.2.3 The effect of China's OFDI across different groups of covariates

The double-edged sword effect of China's OFDI across different groups of covariates of carbon intensity which reflect the heterogeneous characteristics of BRI countries are reported in Table 8.

Table 8. The promotion, reduction and net effects of China's OFDI on carbon intensity of BRI countries by different groups of covariates.

Covariates (Units)	Low group	Middle group	High group
GDP per capita (US $)	<3395.8	>=3395.8 & <11540.6	>=11540.6
PE (%)	3.99	3.82	3.45
RE (%)	10.18	4.97	5.10
NE (%)	-6.19	-1.15	-1.65
Energy consumption (kg of oil equivalent)	<1185.7	>=1185.7 & <2724.3	>=2724.3
PE (%)	3.65	4.17	3.44
RE (%)	10.39	4.58	5.29
NE (%)	-6.74	-0.41	-1.85
Industry share (%)	<25.52	>=25.52 & <33.91	>=33.91
PE (%)	3.10	4.75	3.42
RE (%)	8.49	6.46	5.32
NE (%)	-5.39	-1.71	-1.90
Urbanization (%)	<50.32	>=50.32 & <69.23	>=69.23
PE (%)	3.85	4.44	2.98
RE (%)	9.93	4.87	5.46
NE (%)	-6.08	-0.43	-2.48
Trade openness (%)	<75.69	>=75.69 & <110.96	>=110.96
PE (%)	3.58	3.82	3.87
RE (%)	8.37	5.79	6.10
NE (%)	-4.79	-1.97	-2.23
Political stability	<-0.737	>=-0.737 & <0.253	>=0.253
PE (%)	3.43	3.48	4.36
RE (%)	8.40	6.87	4.99
NE (%)	-4.97	-3.39	-0.63

Note: PE: promotion effect; RE: reduction effect; NE: net effect;

First of all, the impact of China's OFDI on carbon intensity is different in countries of different economic development levels. The reduction effect of China's OFDI is over 10% in the low group of GDP per capita, yielding a 6.19% net reduction in carbon intensity of host countries. However, the reduction effect of China's OFDI decreases obviously in the middle and high-level groups of GDP per capita, leaving a limited net effect of -1.15% and -1.65% on carbon intensity, respectively. It can be concluded that

FDI from China contributes most to the reduction of carbon intensity in less developed BRI economies, which may due to the significant contribution of China's OFDI on the economic growth and technical progress of these countries. This conclusion can be partly supported by the findings of Mahadevan and Sun (2020), which indicated that China's FDI has a decreasing effect on carbon emissions of low-income BRI countries, whereas having no effect in high and upper middle income BRI countries.

From the low to high levels of energy consumption, the net effect of China's OFDI increases at first and then decreases. FDI from China on average could reduce carbon intensity by 6.74% when the energy consumption of host countries is at a low level. After moving to the middle level of energy consumption, the promotion and reduction effect of China's OFDI appear to be evenly matched due to an obvious decrease of the reduction effect, leaving a quite limited net effect which is close to zero. Nevertheless, at the high level of energy consumption, the net effect of China's OFDI returns back to -1.85% due to the decrease of promotion effect and the increase of reduction effect. Similar conclusions can be drawn on the impact of China's OFDI in BRI countries with different levels of urbanization.

Also, the reduction effect of China's OFDI plays a dominant role in countries with low level of industrialization, whereas in the middle and high-level groups of industrialization, the contribution of China's OFDI on reducing carbon intensity tends to be weakened following a continuous decrease of reduction effect. Therefore, the BRI countries should make more effort to introduce and utilize green technology from FDI after moving to higher degree of industrialization. It is also crucial for BRI countries to upgrade their low-carbon economic system with the process of industrialization.

Trade openness reflects a country's degree of openness and attitude towards the world. Compared to the middle and high-level groups of trade openness, the reduction effect (8.37%) of China's OFDI is significantly stronger in BRI countries with low openness degree, leading to a largest net reduction of 4.79% in carbon intensity. By contrast, the promotion effect of China's OFDI tends to be stronger in BRI countries with higher degree of openness. This may be due to the fact that to attract trade and investment cooperation, taxation and environmental regulations in these countries are usually less restricted. As a consequence, countries with higher levels of openness are more likely to become the pollution transfer destinations. It also could be noticed that China's OFDI contributes more to the reduction of carbon intensity in BRI countries with relatively low levels of political stability, but left with a limited net impact on carbon intensity of BRI countries with more stable political environment.

4.3 Robustness tests

We run four other two-tier stochastic frontier models to check the robustness of the estimated results from model (6). The estimation results of the robustness tests are presented in Table 9.

Table 9. The estimation results of two-tier stochastic frontier models for robustness test

	(7) lnCOFDI. L1	(8) lnGDPPC. L1	(9) Pre-BRI Period	(10) Post-BRI Period
lnGDPPC	-0.929***		-0.967***	-0.866***
	(0.0001)		(0.0001)	(0.006)
lnGDPPC. L1		-0.917***		
		(0.0001)		
Promotion Effect				
lnCOFDI(Z_w)		0.010***	0.024***	0.016***
		(0.0004)	(0.003)	(0.002)
lnCOFDI. L1(Z_w)	0.020***			
	(0.001)			
σ_w	0.105***	0.124***	0.100***	0.126***
	(0.006)	(0.003)	(0.007)	(0.017)
Reduction Effect				
lnCOFDI(Z_u)		0.026***	0.026***	0.049***
		(0.001)	(0.004)	(0.003)
lnCOFDI. L1(Z_u)	0.020***			
	(0.001)			
σ_u	0.161***	0.146***	0.156***	0.060***
	(0.006)	(0.003)	(0.013)	(0.008)
σ_v	0.000	0.000	0.000	0.000
	(0.0005)	(0.0005)	(0.001)	(0.004)
Control variables	YES	YES	YES	YES
Observations	784	784	504	280
Log-likelihood	-26.26	-34.52	-46.26	33.20
AIC	112.5	129.0	144.5	-22.41

Note: lnCOFDI.L1: lnCOFDI lagged in one period; lnGDPPC.L1: lnGDPPC lagged in one period; Significance at 0.01, 0.05, and 0.10 levels indicated by ***, **, *; Standard errors in parentheses.

4.3.1 Regression with one-period lagged China's OFDI

Lagged explanatory variables are a common strategy in response to endogeneity concerns in regression data (Bellemare et al., 2017). The main explanatory variable, i.e., the stock of China's OFDI, is lagged by one time period in model (7) to check for the potential endogeneity problems in model estimation. The results of model (7) show that the coefficients of China's OFDI lagged in one period, i.e., $\mathrm{lnCOFDI.L1}(Z_w)$ and $\mathrm{lnCOFDI.L1}(Z_u)$, both are still significant and stable, which verifies the robustness of our estimations.

4.3.2 Regression with one-period lagged GDP per capita

Considering that there might be a two-way causal relationship between the current GDP per capita and carbon intensity, we substitute the GDP per capita in current period with the GDP per capita that is lagged by one period in model (8) to avoid the influence of the possible causal relationship between the current GDP per capita and carbon intensity on parameter estimations. The results from model (8) show that the estimations of major parameters, i.e., $\mathrm{lnCOFDI}(Z_w)$, σ_w, $\mathrm{lnCOFDI}(Z_u)$, and σ_u, are still significant and consistent with the estimations from model (6), which also verifies the robustness of our estimations.

4.3.3 Regressions for subsamples over different periods

We further divide the full sample into pre-BRI period (2005-2013) and post-BRI period (2014-2018) and re-estimate the two-tier stochastic frontier model to test the significance of the double-edged sword effect of China's OFDI before and after the BRI was launched. The estimation results for samples of pre-BRI period and post-BRI period as shown in models (9) and (10), respectively. The results of models (9) and (10) demonstrate that the promotion and reduction effects of China's OFDI on carbon intensity of BRI countries are both still significant in pre-BRI period and post-BRI period, further confirming that the FDI from China can be a double-edged sword for low-carbon development of BRI countries.

Therefore, we can conclude that the main conclusions of this study still hold as reflected from the robustness test results.

5. Conclusion and policy implications

This study estimates the magnitude of the promotion, reduction and net effects of China's OFDI on carbon intensity of 56 major BRI countries based on a two-tier stochastic frontier methodology. The main conclusions are as follows:

First, our results indicate that China's OFDI has both promotion effect and reduction effect on carbon intensity of BRI region, which is a double-edged sword for low-carbon development of host countries. As a result of the neutralization of the two-sided effects, China's OFDI on average contributes to a net reduction in carbon intensity of sample countries by approximately 3.0% during sample period, which as a whole is beneficial for low-carbon development of BRI region.

Second, the net effects of China's OFDI on carbon intensity of BRI countries are all less than zero and vary within a small range over years. Although the net effect of China's OFDI has increased at the early stage of BRI, a downward trend of the net effect with a reduced promotion effect is witnessed later. Therefore, it is foreseeable that the investment cooperation between China and BRI countries will go towards a more sustainable direction with the continuous efforts from both sides.

Third, the two-sided effects of China's OFDI across different BRI countries vary widely. The promotion effect of China's OFDI is higher than the reduction effect in 19 among 56 sample countries, while the reduction effect plays a dominant role in other 37 countries. It can be seen that China's OFDI plays a relatively positive role in contributing towards low-carbon development in a wider range of BRI countries. Nevertheless, the net effect of China's OFDI in several major destination countries has increased obviously after the BRI was launched, such as Vietnam, Laos, Myanmar, and Tajikistan. Therefore, there is still pressure for China and BRI countries to further promote low-carbon development of BRI region with deepening investment cooperation.

Fourth, the effect of China's OFDI on carbon intensity varies depending on the development characteristics of BRI countries. In general, China's OFDI contributes most to the reduction of carbon intensity in less developed BRI countries with low levels of energy consumption, industrialization, and urbanization. By contrast, the net reduction on carbon intensity from China's OFDI is diminished significantly in countries with the middle and high-levels of GDP per capita, energy consumption and urbanization. In particular, the promotion effect of China's OFDI almost catches up with the reduction effect in the middle level groups of energy consumption and urbanization, leaving a limited net effect which is close to zero.

The above conclusions have certain realistic policy implications for both China and BRI partner countries to ensure sustainable cooperation under BRI and jointly promote low-carbon development of BRI region.

First, China should stay committed to a low-carbon and sustainable mode of cooperation, develop supporting system for cooperation with BRI countries in terms of environmental protection, industrial technological cooperation, and risk prevention and service provision. Meanwhile, Chinese overseas enterprises should be regulated to observe the environmental standards of host countries and relevant international regulations. In order to better enhance the technology spillover effect of China's FDI in BRI countries, Chinese enterprises should be encouraged to adopt different types of strategies such as low-carbon technologies transfers, renewable energy projects, and green financial cooperation to achieve greener and more sustainable investment.

Second, the BRI countries in which China's OFDI has a net reduction effect on carbon intensity could continue to develop preferential policies to encourage foreign investment from China to develop their economy. Whereas for BRI countries with huge energy demands, such as the manufacturing countries and newly industrialized countries, it is necessary to improve energy efficiency by actively introducing green technologies and using energy-serving equipment while utilizing foreign capital to develop the economy. For investment in energy intensive industries, local government should establish strict environmental regulations to lessen the environmental impact arising from foreign enterprises. Meanwhile, BRI countries could also try to attract foreign investment in low-carbon sectors and renewable energy industries, speed up energy transition to shift from fossil fuels towards the use of cleaner energy. It is also important for different countries to implement targeted policies corresponding to their own stages and characteristics of economic development path.

Third, to ensure that the BRI region follows a climate-smart, inclusive-growth pathway, China and BRI partner countries, as well as relevant international organizations should co-build research platforms with scientific research institutions and universities to provide intellectual support and reference for promoting low-carbon development of BRI region. The BRI countries could also collaborate with neighboring countries and third parties to learn advanced experiences on the absorption of technical spillovers from foreign investment and effective strategies for low-carbon transformation.

Appendix

Table A1. The 3-digit country code of sample countries included in this study

ID	Country name	Country code	ID	Country name	Country code
1	Albania	ALB	29	Lithuania	LTU
2	United Arab Emirates	ARE	30	Latvia	LVA
3	Azerbaijan	AZE	31	Moldova	MDA
4	Bangladesh	BGD	32	North Macedonia	MKD
5	Bulgaria	BGR	33	Myanmar	MMR
6	Bahrain	BHR	34	Mongolia	MNG
7	Bosnia and Herzegovina	BIH	35	Malaysia	MYS
8	Belarus	BLR	36	Nepal	NPL
9	Brunei	BRN	37	Oman	OMN
10	Czech	CZE	38	Pakistan	PAK
11	Egypt	EGY	39	Philippines	PHL
12	Estonia	EST	40	Poland	POL
13	Georgia	GEO	41	Qatar	QAT
14	Croatia	HRV	42	Romania	ROU
15	Hungary	HUN	43	Russia	RUS
16	Indonesia	IDN	44	Saudi Arabia	SAU
17	India	IND	45	Singapore	SGP
18	Iran	IRN	46	Serbia	SRB
19	Iraq	IRQ	47	Slovakia	SVK
20	Israel	ISR	48	Slovenia	SVN
21	Jordan	JOR	49	Thailand	THA
22	Kazakhstan	KAZ	50	Tajikistan	TJK
23	Kyrgyzstan	KGZ	51	Turkmenistan	TKM
24	Cambodia	KHM	52	Turkey	TUR
25	Kuwait	KWT	53	Ukraine	UKR
26	Laos	LAO	54	Uzbekistan	UZB
27	Lebanon	LBN	55	Vietnam	VNM
28	Sri Lanka	LKA	56	Yemen	YEM

References

Acheampong, A. O., Adams, S., & Boateng, E. (2019). Do globalization and renewable energy contribute to carbon emissions mitigation in Sub-Saharan Africa? *Science of the Total Environment*, *677*, 436-446.

Adeel-Farooq, R. M., Riaz, M. F., & Ali, T. (2021). Improving the environment begins at home: Revisiting the links between FDI and environment. *Energy*, *215*, 119150.

Ahmad, M., Jiang, P., Majeed, A., & Raza, M. Y. (2020). Does financial development and foreign direct investment improve environmental quality? Evidence from belt and road countries. *Environmental Science and Pollution Research*, *27*(19), 23586-23601.

Antweiler, W., Copeland, B. R., & Taylor, M. S. (2001). Is free trade good for the environment? *American Economic Review*, *91*(4), 877-908.

Anwar, M. A., Nasreen, S., & Tiwari, A. K. (2021). Forestation, renewable energy and environmental quality: Empirical evidence from Belt and Road Initiative economies. *Journal of Environmental Management*, *291*, 112684.

Bellemare, M. F., Masaki, T., & Pepinsky, T. B. (2017). Lagged explanatory variables and the estimation of causal effect. *The Journal of Politics*, *79*(3), 949-963.

Buhari, D. Ğ. A., Lorente, D. B., & Nasir, M. A. (2020). European commitment to COP21 and the role of energy consumption, FDI, trade and economic complexity in sustaining economic growth. *Journal of Environmental Management*, *273*, 111146.

Cai, X., Che, X., Zhu, B., Zhao, J., & Xie, R. (2018). Will developing countries become pollution havens for developed countries? An empirical investigation in the Belt and Road. *Journal of Cleaner Production*, *198*, 624-632.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. *Ecological Economics*, *48*(1), 71-81.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological Economics*, *49*(4), 431-455.

Dong, K., Wang, B., Zhao, J., & Taghizadeh-Hesary, F. (2022). Mitigating carbon emissions by accelerating green growth in China. *Economic Analysis and Policy, 75*, 226-243.

Ehigiamusoe, K. U., Lean, H. H., & Smyth, R. (2020). The moderating role of energy consumption in the carbon emissions-income nexus in middle-income countries. *Applied Energy, 261*, 114215.

Eskeland, G. S., & Harrison, A. E. (2003). Moving to greener pastures? Multinationals and the pollution haven hypothesis. *Journal of Development Economics*, *70*(1), 1-23.

Fan, J.-L., Da, Y.-B., Wan, S.-L., Zhang, M., Cao, Z., Wang, Y., & Zhang, X. (2019). Determinants of carbon emissions in 'Belt and Road initiative'countries: a production technology perspective. *Applied Energy*, *239*, 268-279.

Foo, N., Lean, H. H., & Salim, R. (2020). The impact of China's one belt one road initiative on international trade in the ASEAN region. *The North American Journal of Economics and Finance, 54*, 101089.

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *The Quarterly Journal of Economics*, *110*(2), 353-377.

Hao, Y., Ba, N., Ren, S., & Wu, H. (2021). How does international technology spillover affect China's carbon emissions? A new perspective through intellectual property protection. *Sustainable Production and Consumption*, *25*, 577-590.

Hao, Y., Guo, Y., Guo, Y., Wu, H., & Ren, S. (2020). Does outward foreign direct investment (OFDI) affect the home country's environmental quality? The case of China. *Structural Change and Economic Dynamics*, *52*, 109-119.

Hussain, J., Khan, A., & Zhou, K. (2020). The impact of natural resource depletion on energy use and CO2 emission in Belt & Road Initiative countries: a cross-country analysis. *Energy*, *199*, 117409.

Jiang, M., An, H., Gao, X., Liu, S., & Xi, X. (2019). Factors driving global carbon emissions: A complex network perspective. *Resources, Conservation and Recycling*, *146*, 431-440.

Jiang, M., An, H., Gao, X., Zheng, H., & Li, Y. (2021). Identifying the key sectors in the carbon emission flows along the production chain paths: A network perspective. *Ecological Indicators*, *130*, 108050.

Kumbhakar, S. C., & Parmeter, C. F. (2009). The effects of match uncertainty and bargaining on labor market outcomes: evidence from firm and worker specific estimates. *Journal of Productivity Analysis*, *31*(1), 1-14.

Lee, H. S., Arestis, P., Chong, S. C., Yap, S., & Sia, B. K. (2022). The heterogeneous effects of urbanisation and institutional quality on greenhouse gas emissions in Belt and Road Initiative countries. *Environmental Science and Pollution Research*, 29(1), 1087-1105.

Li, X., Liu, C., Wang, F., Ge, Q., & Hao, Z. (2021). The effect of Chinese investment on reducing CO2 emission for the Belt and Road countries. *Journal of Cleaner Production*, *288*, 125125.

Liobikienė, G., & Butkus, M. (2019). Scale, composition, and technique effects through which the economic growth, foreign direct investment, urbanization, and trade affect greenhouse gas emissions. *Renewable Energy*, *132*, 1310-1322.

Liu, H., Wang, Y., Jiang, J., & Wu, P. (2020). How green is the "Belt and Road Initiative"?–Evidence from Chinese OFDI in the energy sector. *Energy Policy*, *145*, 111709.

Liu, L., Zhao, Z., Su, B., Ng, T. S., Zhang, M., & Qi, L. (2021). Structural breakpoints in the relationship between outward foreign direct investment and green innovation: An empirical study in China. *Energy Economics*, *103*, 105578.

Liu, Y., Yao, X., & Wei, T. (2019). Energy efficiency gap and target setting: A study of information asymmetry between governments and industries in China. *China Economic Review*, *57*, 101341.

Ma, S. (2022). Growth effects of economic integration: New evidence from the Belt and Road Initiative. *Economic Analysis and Policy, 73*, 753-767.

Mahadevan, R., & Sun, Y. (2020). Effects of foreign direct investment on carbon emissions: Evidence from China and its Belt and Road countries. *Journal of Environmental Management*, *276*, 111321.

Malik, M. Y., Latif, K., Khan, Z., Butt, H. D., Hussain, M., & Nadeem, M. A. (2020). Symmetric and asymmetric impact of oil price, FDI and economic growth on carbon emission in Pakistan: Evidence from ARDL and non-linear ARDL approach. *Science of the Total Environment*, *726*, 138421.

Muhammad, S., & Long, X. (2021). Rule of law and CO2 emissions: a comparative analysis across 65 belt and road initiative (BRI) countries. *Journal of Cleaner Production*, *279*, 123539.

Muhammad, S., Long, X., Salman, M., & Dauda, L. (2020). Effect of urbanization and international trade on CO2 emissions across 65 belt and road initiative countries. *Energy*, *196*, 117102.

Nepal, R., Paija, N., Tyagi, B., & Harvie, C. (2021). Energy security, economic growth and environmental sustainability in India: Does FDI and trade openness play a role? *Journal of Environmental Management*, *281*, 111886.

Neves, S. A., Marques, A. C., & Patrício, M. (2020). Determinants of CO2 emissions in European Union countries: does environmental regulation reduce environmental pollution?. *Economic Analysis and Policy*, *68*, 114-125.

Nguyen, D. K., Huynh, T. L. D., & Nasir, M. A. (2021). Carbon emissions determinants and forecasting: Evidence from G6 countries. *Journal of Environmental Management*, *285*, 111988.

Pao, H.-T., & Tsai, C.-M. (2011). Multivariate Granger causality between CO2 emissions, energy consumption, FDI (foreign direct investment) and GDP (gross domestic product): evidence from a panel of BRIC (Brazil, Russian Federation, India, and China) countries. *Energy*, *36*(1), 685-693.

Parmeter, C. F. (2018). Estimation of the two-tiered stochastic frontier model with the scaling property. *Journal of Productivity Analysis*, *49*(1), 37-47.

Rauf, A., Liu, X., Amin, W., Rehman, O. U., Li, J., Ahmad, F., & Bekun, F. V. (2020). Does sustainable growth, energy consumption and environment challenges matter for Belt and Road Initiative feat? A novel empirical investigation. *Journal of Cleaner Production*, *262*, 121344.

Shi, Q., Shan, Y., Zhong, C., Cao, Y., & Xue, R. (2022). How would GVCs participation affect carbon intensity in the "Belt and Road Initiative" countries? *Energy Economics*, 106075.

Song, W., Mao, H., & Han, X. (2021). The two-sided effects of foreign direct investment on carbon emissions performance in China. *Science of the Total Environment*, *791*, 148331.

Su, X., Li, Y., Fang, K., & Long, Y. (2022). Does China's direct investment in "Belt and Road Initiative" countries decrease their carbon dioxide emissions? *Journal of Cleaner Production*, *339*, 130543.

Sun, H., Attuquaye Clottey, S., Geng, Y., Fang, K., & Clifford Kofi Amissah, J. (2019). Trade openness and carbon emissions: Evidence from belt and road countries. *Sustainability*, *11*(9), 2682.

Sun, X., & Shi, Q. (2021). Factors influencing embodied energy trade between the Belt and Road countries: a gravity approach. *Environmental Science and Pollution Research*, 1-16.

Waheed, R., Sarwar, S., & Wei, C. (2019). The survey of economic growth, energy consumption and carbon emission. *Energy Reports*, *5*, 1103-1115.

Walter, I., & Ugelow, J. L. (1979). Environmental policies in developing countries. *Ambio*, 102-109.

Wang, J., Dong, K., Dong, X., & Jiang, Q. (2021). Research on the carbon emission effect of the seven regions along the Belt and Road—based on the spillover and feedback effects model. *Journal of Cleaner Production*, *319*, 128758.

World Bank. (2019). Belt and Road Economics: Opportunities and risks of transport corridors. The World Bank. https://doi.org/10.1596/978-1-4648-1392-4.

World Bank. (2022). World bank open data | data. https://data.worldbank.org/.

Wu, H., Ren, S., Yan, G., & Hao, Y. (2020). Does China's outward direct investment improve green total factor productivity in the "Belt and Road" countries? Evidence from dynamic threshold panel model analysis. *Journal of Environmental Management*, *275*, 111295.

Wu, Y., Chen, C., & Hu, C. (2021). Does the Belt and Road Initiative Increase the Carbon Emission Intensity of Participating Countries? *China & World Economy*, *29*(3), 1-25.

Yang, T., Dong, Q., Du, Q., Du, M., Dong, R., & Chen, M. (2021). Carbon dioxide emissions and Chinese OFDI: From the perspective of carbon neutrality targets and environmental management of home country. *Journal of Environmental Management*, *295*, 113120.

Yang, Y., Wang, H., Löschel, A., & Zhou, P. (2022). Patterns and determinants of carbon emission flows along the Belt and Road from 2005 to 2030. *Ecological Economics*, *192*, 107260.

Yu, P., Cai, Z., & Sun, Y. (2021). Does the emissions trading system in developing countries accelerate carbon leakage through OFDI? Evidence from China. *Energy Economics*, 105397.

Yu, S., Qian, X., & Liu, T. (2019). Belt and road initiative and Chinese firms' outward foreign direct investment. *Emerging Markets Review*, *41*, 100629.

Yu, Y., & Xu, W. (2019). Impact of FDI and R&D on China's industrial CO2 emissions reduction and trend prediction. *Atmospheric Pollution Research*, *10*(5), 1627-1635.

Zarsky, L. (1999). Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment. *Foreign direct Investment and the Environment*, *13*(8), 47-74.

Zhang, C., & Zhou, X. (2016). Does foreign direct investment lead to lower CO2 emissions? Evidence from a regional analysis in China. *Renewable and Sustainable Energy Reviews*, *58*, 943-951.

Zhuang, Y., Yang, S., Razzaq, A., & Khan, Z. (2021). Environmental impact of infrastructure-led Chinese outward FDI, tourism development and technology innovation: A regional country analysis. *Journal of Environmental Planning and Management*, 1-33.