RESEARCH ON THE IMPACT OF COORDINATED DEVELOPMENT OF CHINA'S TWO-WAY FOREIGN DIRECT INVESTMENT ON CARBON EMISSIONS IN THE BELT AND ROAD COUNTRIES

HU, H.[1*] – DENG, Y. Y.[2]

[1]*School of Economics and Management, Shaoyang University, Shaoyang, Hunan 422000, China*

[2]*Disciplinary Committee, Shaoyang College, Shaoyang, Hunan 422000, China*

**Corresponding author*
e-mail: huhui0620@163.com; phone: +86-138-0739-7623

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Abstract. The year-on-year increase in carbon emissions poses a serious challenge to global sustainable development. Promoting the reduction of carbon emissions through the coordinated development of two-way foreign direct investment (CDFDI) and thus the green transformation of the global economy is an urgent issue. This study theoretically explains how the CDFDI affects carbon emissions. It empirically tests the carbon emission effect of CDFDI in China using country-level panel data from 2003 to 2021. The study finds that: (1) China's CDFDI has a significant inhibitory effect on the carbon emissions of the Belt and Road (B&R) countries, and this conclusion still holds after the endogeneity discussion and robustness test. (2) From the perspective of the impact mechanism, China's CDFDI reduces the carbon emissions of the B&R countries through the three paths of scale, structural, and technology effects. The carbon emission reduction effect of the coordinated development of China's two-way FDI is further strengthened by the effect of environmental regulation. (3) Further analysis found that the impact of China's CDFDI on the carbon emissions of the B&R countries varies by country, stage, infrastructure, and the level of CDFDI. The conclusions of this study are of great practical significance for China to expand the scale of two-way investment, optimize the structure of two-way investment, reduce the carbon emissions of the B&R countries, and thus promote global green and sustainable development.
Keywords: *coordinated development of IFDI and OFDI, carbon emissions reduction, transmission effect model, moderation effect model, environmental regulations, sustainable development*

Introduction

In an era defined by a worsening climate and economic strains, achieving a harmonious balance between economic advancement and environmental sustainability has emerged as a paramount concern for researchers and policymakers alike. In this context, the low-carbon economic model has gained worldwide recognition. As a key player, China has signed the Belt and Road Initiative (BRI) cooperation agreements with over 150 countries and 30 international organizations, most of which are developing nations across the globe. These BRI partner countries, representing one of the world's fastest-growing economic regions, face dual challenges of surging energy demand and rapid growth in carbon emissions, making their transition to a low-carbon economy imperative. Notably, data from the U.S. Energy Information Administration indicates that BRI countries (including China) account for approximately 60% of global carbon emissions (U.S. Energy Information Administration, 2021). Concurrently, China's cumulative two-way foreign direct investment (FDI) with BRI countries over the past decade has exceeded 380 billion US dollars, comprising over 240 billion U.S.

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dollars in China's outward foreign direct investment (OFDI) and over 140 billion U.S. dollars in inward foreign direct investment (IFDI) (The State Council Information Office of the People's Republic of China, 2023). Furthermore, according to statistics from the United Nations Conference on Trade and Development (UNCTAD), China's two-way FDI (including IFDI and OFDI) demonstrated a steady growth trend between 2003 and 2021, indicating that China is currently in a phase of balanced development of both IFDI and OFDI (UNCTAD, 2022). The specific trend is illustrated in *Figure 1*. Consequently, it is essential to analyze the drivers of carbon emissions in the B&R countries from the perspective of China's coordinated two-way FDI development, to guide their sustainable development and provide valuable insights for global carbon reduction.

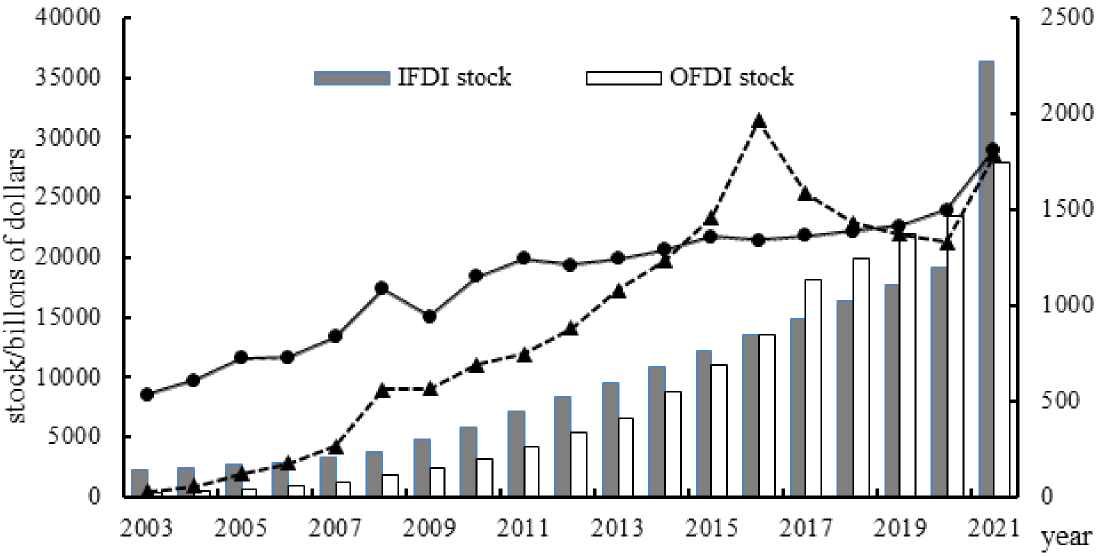

Figure 1. *Trends in China's two-way FDI from 2003 to 2021*

The complex relationship between two-way FDI and carbon emissions has been explored through several interconnected research streams.

First, the nature of the relationship between IFDI and OFDI remains debated. Some scholars argue for a complementary relationship, where one promotes the other (Apergis, 2008; Fu and Lin, 2021), while others posit a substitutive relationship (Kristjánsdóttir, 2012). Factors influencing this interaction include government macro-control (Marton and McCarthy, 2007), trade openness (Chen et al., 2020), infrastructure levels (Tian and Wang, 2017), and factor linkages (Li et al., 2022; Yao et al., 2016). Given the evolving trajectory of China's two-way FDI, recent research has increasingly focused on its measurement and quantification, influencing factors, and impact effects (Xu et al., 2022; Ma et al., 2023).

Second, a vast body of literature examines the drivers and mitigation pathways of carbon emissions. Economic growth is consistently identified as a primary driver of emissions increases (Shahiduzzaman et al., 2015; Lan et al., 2016; Rüstemoğlu et al., 2016), albeit with stage-specific variations (Pani and Mukhopadhyay, 2010). Population size and urbanization levels also exert significant positive influences (Shi, 2003; Wang et al., 2021; Yao et al., 2015). Conversely, factors such as industrial structure optimization (Stefanski, 2009), technological innovation (Yabe, 2004), changes in energy structure

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(Zhang et al., 2012; Farhani, 2013), and shifts in development models are key to reducing emissions. Methodologies for measuring emissions, including actual measurement, inventory analysis, and model estimation, continue to be refined (Dagoumas and Barker, 2010; Kang et al., 2020; Li et al., 2022). In terms of mitigation pathways, strategies range from implementing stricter environmental regulations (Zhao and Zhu, 2022) to leveraging international initiatives like the BRI itself, which has been found to reduce carbon emissions in participating regions (Yu et al., 2023).

Third, research directly linking CDFDI to carbon emissions is nascent and stems from the theoretical foundations of the Pollution Haven Hypothesis (Baumol and Oates, 1988) and the Pollution Halo Hypothesis (Zarsky, 1999). While studies examining the impact of either IFDI or OFDI on carbon emissions in isolation are abundant (He, 2006; Bakhsh et al., 2017; Mahadevan and Sun, 2020; Ren et al., 2021; Tan et al., 2021; Yang et al., 2021), research treating two-way FDI as an integrated system is scarce. Since Yao et al. (2016) identified a dynamic relationship between China's IFDI and OFDI, a small but growing number of studies have begun to explore the CDFDI and its impact on carbon emissions, primarily within China. Most find that such coordination significantly reduces CO_2 emissions at the national or regional level (Wang et al., 2019, 2022a; Xiang and Dai, 2022; Wang and Duan, 2023; Qiu et al., 2024), though some report an increase in regional carbon emission intensity (Zhu et al., 2022). The role of environmental regulation has also been introduced, with evidence suggesting that the combination of CDFDI and strong environmental regulation can enhance carbon productivity (Wang et al., 2022b).

Despite these contributions, significant research gaps persist, which this study aims to address. Firstly, while some literature incorporates two-way FDI, many studies still analyze its components separately (Luo et al., 2020; Cai et al., 2021; You et al., 2022), and the net effect on emissions remains contentious. Second, the focus has overwhelmingly been on China's domestic emissions, with a critical lack of research on how China's CDFDI affects carbon emissions in BRI partner countries. Third, the mechanisms through which two-way FDI affects emissions are often limited to scale, structural, and technology effects, overlooking the potential moderating role of environmental regulation in the host countries (Wang et al., 2019).

To fill these gaps, this paper selects a sample of 77 the BRI countries (see *Table A1* in the *Appendix*) from 2003 to 2021 to empirically investigate the impact of China's CDFDI on their carbon emissions. The marginal contributions of this study are threefold: (1) Constructing a theoretical model to analyze the impact of two-way FDI coordination development on carbon emissions, incorporating the moderating role of host country environmental regulation; (2) Empirically testing the carbon emission effects using a two-way fixed effects model, examining the mediating roles of economic scale, industrial structure, and technological progress, and further validating the moderating effect of environmental regulation on these pathways; (3) Exploring heterogeneous effects across different country groups, time periods, and levels of infrastructure development.

This research seeks to analyze the impact of China's CDFDI on carbon emissions in B&R countries and its transmission mechanisms. Specifically, it focuses on the moderating role of host country environmental regulation, a critical yet understudied factor. The rest of the paper is organized as follows: Theoretical analysis, Research methods, Research results, Discussion, Conclusions, Recommendations and outlook.

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Theoretical analysis

The effect of two-way FDI on carbon emissions can be either positive or negative, and if it reduces a country's carbon emissions while increasing those of other countries, it will not contribute to global carbon reduction. Therefore, a country can try to reduce its own and other countries' carbon emissions by coordinating the development of two-way FDI. Therefore, this paper follows the idea of trade environment effect model constructed by Grossman and Kruege (1993), Copeland and Taylor (1994), Antweiler et al. (2001) and Hao et al. (2020) scholars, and innovatively introduces the variable of CDFDI and constructs a theoretical model to analyze the impact of CDFDI on carbon emission. We introduce the variable of CDFDI, construct the theoretical model analytical framework of the impact of two-way FDI on carbon emissions, explore the mechanism of CDFDI on carbon emissions in-depth, and expand and extend on this basis.

Theoretical modeling and derivation

Basic assumptions and production function

To construct a theoretical model for analyzing the carbon emission effects of coordinated development in IFDI and OFDI, this paper adopts a two-sector framework within an open economy. The model is built on the following core assumptions.

(1) Sectoral Classification and Carbon Emission Intensity: The economy produces two types of goods: a relatively clean good (A) and a relatively pollution-intensive good (B). This classification is predicated on a significant divergence in their carbon emission intensities (CO_2 emissions per unit of output).

Department B of polluting products employs traditional production techniques, resulting in a high and positive emission intensity (ε_B > 0).

In contrast, Department A of cleaning products extensively adopts advanced decarbonization technologies. As a theoretical benchmark and to clearly reveal the core mechanism by which CDFDI influences carbon emissions through the reallocation of capital factors across sectors (i.e., the "structural effect"), this model sets the carbon emission intensity of Department A to be approximately zero (ε_A≈0). This aims to establish an ideal reference framework to highlight the driving role of technological differences between sectors. We acknowledge that absolute zero emissions are difficult to achieve from a product lifecycle perspective, but this simplification is both feasible and necessary for theoretical derivation (Copeland and Taylor, 2003; Wang et al., 2022b).

(2) Production Technology and Market Structure: Both sectors require capital (K) and labor (L) as inputs, with production functions exhibiting constant returns to scale. Assuming unit prices of clean product A and polluting product B are P_A and P_B respectively. The objective of a firm is to maximize profits. In the theoretical model, we temporarily disregard the cost of carbon emissions. Thus, the production functions for clean and polluting products are:

$$A = F_1(K_A, L_A) \qquad \text{(Eq.1)}$$

$$B = F_2(K_B, L_B) \qquad \text{(Eq.2)}$$

where A represents the total output of clean products. Since their CO_2 emission intensity during production is approximately zero, the net output A aligns with the potential output

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$F_1(K_A, L_A)$. B denotes the total output of producing polluting products, because there are CO_2 emissions in the production of B, so assuming that the enterprise invests Φ ($0 < \Phi < 1$) portion of the factors to manage carbon emissions, then the factors for the production of product B are only left with the (1-Φ) portion of the factors, and so the product B's production function can be transformed into:

$$B = (1-\Phi)F_2(K_B, L_B) \quad \text{(Eq.3)}$$

It can be seen from *Equation 3* that the total output of polluting product B is affected by two factors: one is the proportion of the input factors of the product in carbon emission control; the second is the potential output of $F_2(K_B, L_B)$ product B. In the production of polluting product B, the more elements (technology T and capital K) invested in carbon emission control, the lower the output of polluting product B, so the net output of B product is less than its potential output.

Finally, since carbon emissions are closely related to the production of product B and pollution control activities, the production function of carbon emissions can be expressed as follows, assuming that the carbon emission control function is:

$$CO_2 = w(\Phi)[F_2(K_B, L_B)] \quad \text{(Eq.4)}$$

where CO_2 represents the carbon emissions generated by the enterprise in the production of polluting products B and exists $w(\Phi) > 0$, $w'(\Phi) < 0$, $w''(\Phi) > 0$, this shows that it is a monotone decreasing function $w(\Phi)$. In other words, when there is no carbon governance ($\Phi = 0$), carbon emissions are equal to the potential output of product B; when enterprises use all elements for carbon emission control, carbon emissions will be reduced to 0. So we found that CO_2 emissions decreased with the increase in its governance costs. At the same time, the change in a country's CO_2 emissions will also be affected by its technical level T. The rise of the technical level will promote the continuous progress of carbon management technology in economic activities, thus reducing CO_2 emissions. Therefore, we set the CO_2 emissions per unit output value of a country's production of polluting products as the following expression:

$$w(\Phi) = T^{-1}(1-\Phi)^{1/\sigma} \quad \text{(Eq.5)}$$

where T represents the low-carbon technology level in the production process, whichσ is a function parameter, and $0 < \sigma < 1$, so we find that the higher the low-carbon technology level, the lower the CO_2 emissions. By substituting *Equation 5* into *Equation 4*, the following results can be obtained:

$$CO_2 = T^{-1}(1-\Phi)^{1/\sigma}F_2(K_B,L_B) \quad \text{(Eq.6)}$$

$$(1-\Phi) = [T^*CO_2/F_2(K_B,L_B)]^{\sigma} \quad \text{(Eq.7)}$$

Then, by substituting *Equation 6* into *Equation 3*, we can get:

$$B = (T^*CO_2)^{\sigma}[F_2(K_B,L_B)]^{(1-\sigma)} \quad \text{(Eq.8)}$$

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It can be seen from *Equation 7* that polluting product B is determined by the potential output of its products $[F_2(K_B, L_B)]$ and carbon emissions T^*CO_2.

Production and emission decisions

To maximize profits, enterprises will inevitably produce carbon emissions during the production of product B. In other words, the production of product B will lead to negative externalities and thus increase carbon emissions. Assuming that the treatment cost is, for the enterprise producing product B, to maximize profits, it will make the following decisions:

(1) Under the condition of constant factor inputs, assuming that the prices of capital and labor are w and r, respectively, and remain in a certain proportion, the enterprise will choose the appropriate combination of factors to minimize the cost of the entire production process under the premise of maximizing the potential output F_2, so that there is:

$$B = \mathrm{Min}(wK_B + rL_B) \quad \text{(Eq.9)}$$

$$F_2(K_B + L_B) = \overline{B} \quad \text{(Eq.10)}$$

This represents the potential output of polluting product B, so that the optimal conditions can be derived:

$$\frac{\partial F_2}{\partial K_B} / \frac{\partial F_2}{\partial L_B} = \frac{r}{w} \quad \text{(Eq.11)}$$

(2) Assuming that the unit potential output cost (C^{F2}) and the carbon emission control cost (MC) are fixed, enterprises will choose the best combination of potential output and effective carbon emissions ($T * CO_2$) in the production process to ensure that the cost of producing a unit polluting product B is the lowest (Zhou et al., 2019).

$$\mathrm{Min}\{[MC(T^*CO_2)] + C^{F2}{}^*F_2(K_B, L_B)\} \quad \text{(Eq.12)}$$

$$({}^*CO_2)^{\sigma}[F_2(K_B, L_B)]^{(1\text{-}\sigma)} = B \quad \text{(Eq.13)}$$

This B represents the actual output of the polluting product B, which remains unchanged. Then, solving the first derivative of *Equations 12* and *13*, we can get:

$$(1\text{-}\sigma)^*(T^*CO_2)/\sigma F_2(K_B, L_B) = C_2^F/MC \quad \text{(Eq.14)}$$

It can be seen from the previous article that P_B is the price of polluting product B, so the total income of polluting products is$TR = P_B{}^*B$, the total cost of polluting products $TC = C^{F2}{}^*F_2(K_B,L_B) + MC(T^*CO_2)$ Therefore, it can be concluded that the profit (π) = total income (TR) - total cost (TC) of polluting products produced by enterprises. At the same time, this paper also assumes that the market for producing polluting products is perfectly competitive, so in the equilibrium state, the economic profit of the enterprise is 0, which can be derived:

$$P_B{}^*B = C_2^F{}^*F_2(K_B,L_B) + MC(T^*CO_2) \quad \text{(Eq.15)}$$

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By bring *Equation 14* into *Equation 15*, we can get:

$$CO_2 = \sigma P_B * B/MC * T \tag{Eq.16}$$

It can be seen from *Equation 16* that the CO_2 emissions caused by the production of polluting product B will decrease with the increase of treatment cost (MC) and low-carbon technology level (T), and will also increase with the increase of product B's price. In addition, since P_A is assumed to be the price of the clean product A, the total output of the whole economy is $Scale = P_A A + P_B B$, and the proportion of the output of the polluting product B to the total output is $Stru = P_B B/(P_A A + P_B B)$, both of which are brought into *Equation 15*.

$$CO_2 = (P_A A + P_B B)*[\sigma/MC*T]*(P_B*B)/(P_A A + P_B B) \tag{Eq.17}$$

where $\sigma / MC*T$ represents the technical level of a country, used to *Tec* represent, *Equation 17* can be written as:

$$CO_2 = SCALE*\ STRUC*TEC \tag{Eq.18}$$

The above equation shows that a country's CO_2 emissions are jointly determined by its scale effect (Scale), structural effect (Stru), and technological effect (Tec), and we then take the logarithm of both sides of *Equation 18* at the same time, which can be obtained:

$$lnCO_2 = lnSCALE*lnSTRUC*lnTEC \tag{Eq.19}$$

Derivation of *Equation 19* yields:

$$\frac{dCO_2}{CO_2} = \frac{dSCALE}{SCALE} + \frac{dSTRUC}{STRUC} + \frac{dTEC}{TEC} \tag{Eq.20}$$

It has been found that a country's CO_2 emissions are mainly determined by its level of economic development, industrial structure, and technological progress (Antweiler et al., 2001). From *Equation 20*, it follows that a country's CO_2 emissions will be affected by the scale effect ($\frac{dSCALE}{SCALE}$), structural effect ($\frac{dSTRUC}{STRUC}$), and technology effect ($\frac{dTEC}{TEC}$). Thus, we again deform *Equation 20* to obtain:

$$dCO_2 = dSCALE\frac{CO_2}{SCALE} + dSTRUC\frac{CO_2}{STRUC} + dTEC\frac{CO_2}{TEC} \tag{Eq.21}$$

Assessing the specific impact of CDFDI on carbon emissions, both sides of *Equation 21* are derived simultaneously for CDFDI, from which the following expression is obtained:

$$\frac{dCO_2}{dCDFDI} = \frac{dSCALE}{dCDFDI}\frac{CO_2}{SCALE} + \frac{dSTRUC}{dCDFDI}\frac{CO_2}{STRUC} + \frac{dTEC}{dCDFDI}\frac{CO_2}{TEC} \tag{Eq.22}$$

Let $\frac{CO_2}{SCALE} = \mu_1$, $\frac{CO_2}{STRUC} = \mu_2$, $\frac{CO_2}{TEC} = \mu_3$. Then *Equation 22* can be changed to:

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$$\frac{dCO_2}{dCDFDI} = \mu_1 \frac{dSCALE}{dCDFDI} + \mu_2 \frac{dSTRUC}{dCDFDI} + \mu_3 \frac{dTEC}{dCDFDI} \quad \text{(Eq.23)}$$

From *Equation 23*, it can be introduced that the impact of China’s CDFDI on carbon emissions can also be decomposed into three major effects: scale, structure, and technology, and the direction of the impact of China’s CDFDI on carbon emissions depend on the direction of the impact of the three effects and the size of their combined effect.

Extended analysis

According to Porter’s hypothesis, appropriate environmental regulation can optimize the production structure, save resources and factors, promote green technological innovation, and thus reduce carbon emissions. Considering that the inflow and outflow of two-way FDI may be affected by a country’s environmental regulation, this paper argues that environmental regulation may, to a certain extent, change the direction and size of the mechanism of CDFDI on carbon emissions. Then we put forward the following hypothesis:

Environmental regulation negatively affects carbon emissions

Usually, when enterprises face the double externality dilemma, they may choose not to carry out or delay the low-carbon and zero-carbon practices, which in turn affects the process and effect of green low-carbon development. Thus. Environmental regulation becomes an important initiative for the government to urge enterprises to practice green low-carbon practices and reduce CO_2 emissions (Wang et al., 2022b). From *Equation 16*, it can be seen that the CO_2 emissions caused by the production of pollution-intensive product B are positively correlated with the price of its product, and negatively correlated with the level of low-carbon technology T and the cost of governance MC. Since there is a certain correlation between the price of pollution-intensive products P_B, and the cost of governance MC, then the relationship between the change in carbon emissions and the cost of governance MC is also uncertain. When the level of environmental regulation in a country is high, the cost of carbon emission governance MC is relatively high as well. This will lead to a significant decrease in CO_2 emissions. On the contrary, when a country’s environmental regulation level is low, the carbon emission management cost MC is relatively low, which will lead to a rise in CO_2 emissions. Therefore, the findings suggest that the intensity of environmental regulation may adversely affect carbon emissions.

Environmental regulation can positively regulate the inhibiting effect of two-way FDI coordinated development on carbon emissions.

Firstly, environmental regulation may reduce the scale effect of two-way FDI coordinated development, which is conducive to reducing carbon emissions. Generally speaking, environmental regulation can regulate the scale effect of CDFDI on carbon emissions by influencing the production and operation mode of enterprises. On the one hand, the deepening of environmental regulations increases the production costs of foreign enterprises, which makes a country less attractive for foreign investment, and thus leads to a reduction in FDI inflows, i.e., the scale effect of FDI is reduced (Zhang, 2020). On the other hand, when a country implements stricter environmental regulations, enterprises may choose to invest in countries with lower levels of environmental regulations, which, to a certain extent, will also affect the location choice of enterprises’ foreign investment, and thus affect the scale of OFDI. In short, as the level of environmental regulation rises, it will

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significantly limit the thresholds of FDI entry and OFDI outflow, leading to a decline in the scale of two-way FDI, which in turn reduces carbon emissions.

Secondly, environmental regulation may amplify the structural optimization effect of CDFDI. It will strengthen the inhibiting effect of CDFDI on carbon emissions. On the one hand, environmental regulation will promote the communication and exchange of low-carbon factors among countries. This is conducive to two-way direct investment in the global scope of the optimal allocation, shortening the individual enterprise or even the whole industry optimization and upgrading, promoting a country's economic transformation in the direction of green low-carbon, resulting in a "reverse emission reduction" effect. On the other hand, the implementation of environmental regulatory policies will increase the production costs of enterprises. For their interests, foreign-invested enterprises and outward investment enterprises have to carry out technological innovation, which improves the structural optimization effect of CDFDI (Gong and Liu, 2020). It can be seen that under the effect of environmental regulation, the promotion effect of CDFDI on industrial structure optimization and upgrading is further expanded, which further inhibits carbon emissions.

Finally, environmental regulations may expand the technological spillover effect of - CDFDI, which will strengthen the inhibition of carbon emissions by CDFDI. Theoretically, environmental regulations will regulate the two-way investment structure by restricting the tendency of foreign investment, which will optimize the emission reduction methods and technologies, and thus reduce carbon emissions from the source. In practice, as a country's level of environmental regulation increases, the structure of two-way FDI and the characteristics of synergistic development are also changing. On the one hand, the host country screens and attracts foreign-funded enterprises that are favorable to the national environment and can promote the country's green and low-carbon development requirements, guide them to learn advanced environmental protection technology abroad, open up green markets, expand outward investment, and promote green reverse technology spillover. On the other hand, to reduce the cost of pollution control, high-polluting and high-emission enterprises take the initiative to carry out green technological innovation, which further optimizes the quality of bidirectional FDI inflows and outflows, and not only improves the production efficiency but also reduces carbon emissions. Thus, environmental regulation amplifies CDFDI's positive effect on green total factor productivity (Chen, 2023), further advancing carbon reduction goals.

In summary, environmental regulation ultimately strengthens the inhibiting effect of the coordinated development of two-way FDI (CDFDI) on carbon emissions by narrowing the scale effect of CDFDI, expanding the structural and technological effects of CDFDI. The details are shown in *Figure 2*.

Research methods

Model specification

Based on the theoretical analysis, empirical factual analysis, and empirical analysis at the industry and regional levels in the previous section, this chapter constructs the "country-year" panel data to empirically analyze the impact of China's CDFDI on carbon emissions of the B&R countries and sets up the following benchmark regression model. The following benchmark regression model is set up:

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$$\ln CO_{2_{jt}} = \lambda_1 + \lambda_2 \ln CDFDI_{jt} + \lambda_3 X_{jt} + \varepsilon_{jt} \quad \text{(Eq.24)}$$

where $CO_{2_{jt}}$ is an explanatory variable, representing the carbon emissions of country *j* in year *t*, $CDFDI_{jt}$ is the core explanatory variable, which indicates the China's CDFDI in the B&R countries in the t year; X_{jt} is as a set of control variables, *j*, and *t* represent the country and time fixed effects, respectively; $\boldsymbol{\varepsilon}_{jt}$ is a random perturbation term.

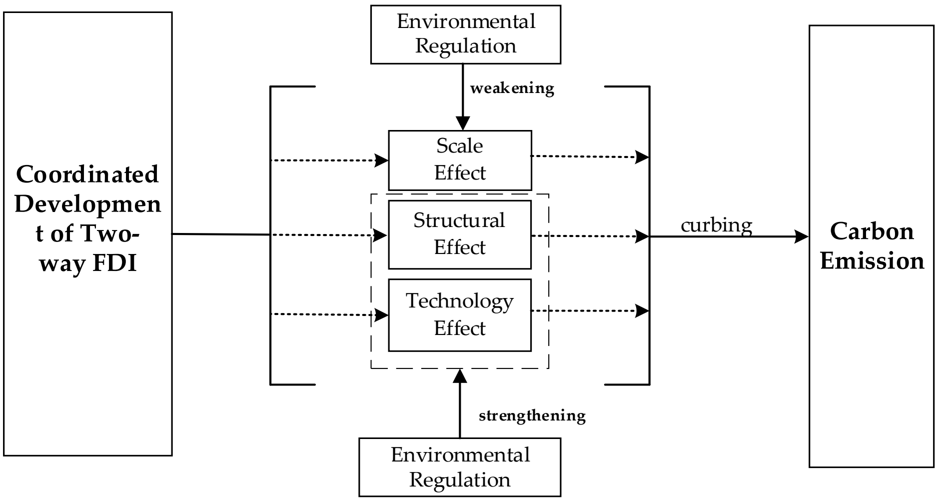

***Figure 2.** Mechanisms of the coordinated development of two-way FDI affecting carbon emissions*

Variable selection and data source

(1) The explained variable of carbon emissions (CO_2): Studies have shown that there are various sources of national carbon emissions data, such as the World Bank, the International Energy Agency, the Global Carbon Budget database, the World Energy Statistics Yearbook, the BP database and so on. Given that the World Bank and other databases for carbon emissions data have only been updated to 2020, this paper chooses the total carbon emissions of each country published in the Global Carbon Budget Database (GCB) as the dependent variable in this paper for regression analysis, and per capita carbon emissions of each country are used in the robustness test for analysis.

(2) The core Explanatory Variables of coordinated development of two-way FDI (CDFDI): referring to Huang et al. (2018), the Coupling Coordination Model is used to measure the level of CDFDI. FDI as a form of transnational investment and production activity, encompasses both the inflow and outflow of international capital. Within the scope of this study, it refers to China's actual utilization of inward foreign direct investment (IFDI) from countries along the Belt and Road, while also encompassing China's outward foreign direct investment (OFDI) activities in the B&R countries. First, considering that there may be some differences between the IFDI and OFDI data, the method of change in deviation is used to standardize them to eliminate the influence of different orders of magnitude and scales. Second, the coupling degree of two-way FDI is calculated using the coupled system model in physics, as shown in *Equation 25*:

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$$C_{it}(IO) = (IFDI_{it}*OFDI_{it})/(\alpha IFDI_{it}*\beta OFDI_{it})^{\gamma} \quad \text{(Eq.25)}$$

where γ is the adjustment coefficient ($2 \leq \gamma \leq 5$), this paper takes the value of 2; and α and β are coefficients to be determined, indicating the importance of IFDI and OFDI in the subsystem. In recent years, due to China's active implementation of the development strategy of "bringing in" and "going out", resulting in the development of IFDI and OFDI of similar size and synchronization trend is very obvious, so this paper considers that IFDI and OFDI are equally important, α and β are both set to 0.5. Finally, given that the coupling degree can only reflect the degree of interaction between the systems, when the IFDI and OFDI coefficients are equal, the coupling degree can only reflect the degree of interaction between the systems. When the values of IFDI and OFDI are small but similar, it will lead to a higher coupling degree, i.e., a "pseudo-coordination" situation. To solve this problem, the coupling coordination degree model is further introduced to measure, and the specific formula is shown in *Equation 26*. The closer the score is to 1, the higher the level of CDFDI is, and vice versa.

$$CDFDI_{it}(IO) = \left\{(IFDI_{it}*OFDI_{it})/[(IFDI_{it} + OFDI_{it})/2]\right\}^{\frac{1}{2}} \quad \text{(Eq.26)}$$

(3) Control variables: ① capital input (*K*), measured by the share of gross capital formation in GDP. ② Trade openness (*TRADE*), measured by the share of merchandise trade in GDP. ③ R&D expenditure (*RD*) input is measured using the share of R&D expenditure in the GDP of each country. ④ Labor input (*L*), measured using the total labor force of each country. ⑤ Population density (*DEN*), measured using the number of people per kilometer of land area. To ensure consistency in data definitions, all raw data for the above control variables are sourced from the World Bank.

Since China has only started to publish OFDI data for all countries since 2003, the data on R&D expenditures for all countries have only been updated to 2021. At the same time, given the availability of data on China's two-way FDI in countries along the Belt and Road. Therefore, this paper selects China's panel data for the B&R countries (a total of 77 countries) from 2003 to 2021 for analysis. To reduce the absolute differences between the data and avoid the influence of individual outliers, the variables in the form of absolute numbers are treated as logarithms. Meanwhile, for the missing values of a few variables, we mainly adopt the linear interpolation method to supplement them. The descriptive statistics of the variables in this chapter are shown in *Table 1*.

Research results

Benchmark regression results

To test the specific impact of the CDFDI on the carbon emissions of the countries along the Belt and Road. This section uses *Equation 24* to perform regression analysis on the collected sample data. According to the results of the F test of the fixed effect model, the LM test, and the Hausman test of the random effect model, the double fixed effect model is finally selected for estimation. The full sample regression results are shown in *Table 2*. *Table 2* shows the regression result without adding control variables, and the estimated coefficient of the core explanatory variable *lnCDFDI* is significantly negative at least at the level of 1%. Preliminary findings indicate that a higher level of two-way FDI coordination between China and B&R countries is associated with lower carbon

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emissions in the latter. After adding control variables step by step, the regression results in columns (2)-(6) show that the coefficient of *lnCDFDI* is still significantly negative. This finding serves as additional confirmation of the significant role of China's CDFDI in reducing carbon emissions across the B&R countries. This supports the "pollution halo effect" hypothesis and aligns with the findings of Wang et al. (2019), Xiang and Dai (2022), Wang and Duan (2023), among other scholars. Next, we interpret the economic meaning of each regression coefficient in detail according to column (6). The estimated coefficient of the CDFDI on carbon emission is -0.1825, which means that for every 1% increase in the level of CDFDI between China and the B&R countries, the carbon emission of the B&R countries will decrease by 0.1825 percentage points.

Table 1. *Descriptive statistics of variables*

Variable	Sample size	Mean	Standard deviation	Median	Minimum	Maximum
$lnCO_2$	1463	8.2222	1.6478	8.2983	4.6728	12.0509
lnCDFDI	1463	-2.9952	0.5438	-3.1466	-3.4420	0
TRADE	1463	71.3779	40.3292	63.1500	5.0800	343.4900
K	1463	24.6031	7.5703	23.7100	2.1700	58.1500
lnL	1463	15.4728	1.3882	15.4450	11.9737	18.7282
RD	1463	0.6760	0.7746	0.4500	0.0100	5.7100
lnDEN	1463	4.3139	1.2543	4.4233	0.4824	8.9829
lnSCALE	1463	24.1609	1.6666	24.2353	18.7727	28.4669
STRUC	1463	3.3056	0.3824	3.2707	1.6752	4.3150
lnTEC	1463	4.9023	2.4268	5.1180	-2.8134	12.1348
lnERI	1463	3.9381	0.3891	3.9982	0.8838	4.4884

Table 2. *Benchmark regression results*

Variable	(1)	(2)	(3)	(4)	(5)	(6)
lnCDFDI	-0.1529***	-0.1701***	-0.2160***	-0.2292***	-0.2184***	-0.1825***
	(0.0286)	(0.0305)	(0.0283)	(0.0260)	(0.0278)	(0.0277)
TRADE		-0.0009*	-0.0008*	0.0009*	0.0011**	0.0012**
		(0.0005)	(0.0005)	(0.0005)	(0.0005)	(0.0005)
K			0.0154***	0.0118***	0.0118***	0.0117***
			(0.0013)	(0.0012)	(0.0012)	(0.0012)
lnL				0.8430***	0.8435***	-0.0092
				(0.0768)	(0.0764)	(0.1411)
RD					-0.0539*	-0.0526*
					(0.0298)	(0.0318)
lnDEN						1.0769***
						(0.1588)
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes
Constant	7.7643***	7.7793***	7.2532***	-5.8635***	-5.8166***	2.8338*
	(0.0861)	(0.0863)	(0.0898)	(1.1971)	(1.1899)	(1.6821)
Observations	1463	1463	1463	1463	1463	1463
R^2	0.9834	0.9834	0.9855	0.9877	0.9877	0.9883

*, * *, * * * represent significant at the 10%, 5%, and 1% levels, respectively. The robust standard errors are in parentheses, and the table below is the same

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Regarding the control variables, capital investment (*K*), trade openness (*TRADE*), and population density (*lnDEN*) exhibit positive and statistically significant coefficients at the 1% level, indicating their positive correlation with carbon emissions in B&R countries. In contrast, R&D investment (*RD*) shows a significantly negative coefficient, supporting its role in fostering low-carbon technology and reducing emissions. Labor input (*lnL*) has an insignificant negative coefficient, suggesting a weak inhibitory effect. Consequently, future policies should prioritize increasing R&D funding and optimizing the allocation of labor and capital.

Mechanism test results

Building upon the preceding theoretical analysis, this section investigates how China's CDFDI affects B&R countries' carbon emissions through economic scale, industrial structure, and technological progress. It further explores how environmental regulation shapes this influence.

Testing the transmission mechanism of economic scale, industrial structure, and technological progress

The environmental Kuznets curve hypothesis states that there is an inverted "U" shaped relationship between economic growth and environmental pollution. That is, carbon emissions increase with economic growth in the early stages of economic development and then begin to decline after a certain threshold is reached. It can be deduced that the CDFDI affects a country's economic development, which in turn leads to changes in the country's carbon emissions. At the same time, a country's attraction to foreign capital and outward investment will also lead to changes in the country's industrial structure, which in turn will have a certain impact on the country's carbon emissions. In addition, from the general equilibrium theoretical model, technological innovation is also an important factor affecting the relationship between international direct investment and carbon emissions. When China conducts two-way FDI in the B&R countries, the countries along the route can acquire China's production experience and low-carbon technologies through technological spillover and reverse technological spillover effects, which will have an impact on their carbon emissions. Therefore, this paper argues that China's CDFDI can also affect the carbon emissions of the B&R countries through the scale effect, structural effect, and technology effect. Therefore, the following transmission effect model is constructed for testing by drawing on the stepwise method proposed by Baron and Kenny (1986).

$$\mathrm{lnw_{jt}} = \mu_1 + \mu_2 \mathrm{lnCDFDI_{jt}} + \mu_3 \mathrm{X_{jt}} + \varepsilon_{jt} \tag{Eq.27}$$

$$\mathrm{lnCO_{2_{jt}}} = \theta_1 + \theta_2 \mathrm{lnCDFDI_{jt}} + \varphi \mathrm{w_{jt}} + \lambda_3 \mathrm{X_{jt}} + \varepsilon_{jt} \tag{Eq.28}$$

where w_{jt} denotes the transmission mechanism variables, which are economic size (*SCALE*), industrial structure (*STRUC*), and technological progress (*TEC)*. The economic scale (*SCALE*) is measured using the GDP of each country and deflated using the GDP deflator with 2000 as the base period. Industrial structure (*STRUC*) is measured using a country's industrial value added as a share of its GDP. The reason is that most of the B&R countries are currently in the process of industrialization, and industry is the main source of carbon emissions in a country, so it is used to indicate the

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industrial structure. Technological progress (*SCALE*) is measured by the total number of patent applications in a country, and the data for the three mechanism variables are all from the World Bank database. φ represents the impact of various mechanism variables on carbon emissions, and the meanings of the other variables are consistent with the baseline regression.

Given that the regression results of step 1 of the conduction effect model have already been reported in the baseline regression, and the coefficient λ_2 is significantly negative, only step 2 and step 3 tests of the conduction effect are needed next. *Table 3* shows that the coefficients μ_2 of the step 2 test of the three conduction effects are significant, and the coefficients θ_2 and φ of the step 3 test are also significant, indicating that the conduction effects of the three mechanism variables exist.

Table 3. *Conduction effect test results*

Variable	(7) *lnSCALE*	(8) *lnCO₂*	(9) *STRUC*	(10) *lnCO₂*	(11) *lnTEC*	(12) *lnCO₂*
lnCDFDI	0.6889*** (0.0606)	-0.1843*** (0.0341)	-0.0633*** (0.0198)	-0.1197*** (0.0277)	0.2657*** (0.0977)	-0.1683*** (0.0285)
lnSCALE		0.0456*** (0.0161)				
STRUC				0.5251*** (0.0415)		
lnTEC						-0.0578*** (0.0087)
Sobel test	0.0314*** （accounting for 20.55%）		-0.0332*** （accounting for 21.73%）		0.0433*** （accounting for 20.08%）	
Bootstrap test	[0.0364，0.1436]		[-0.0020，-0.1324]		[0.5516，0.7599]	
Control variable	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes
Constant	26.2244*** (0.1804)	6.5681*** (0.4323)	3.1161*** (0.0581)	6.1279*** (0.1527)	5.6980*** (0.2966)	7.4346*** (0.0992)
Observations	1463	1463	1463	1463	1463	1463
R^2	0.9542	0.9835	0.8535	0.9856	0.9119	0.9840

The test results of the transmission effect in *Table 3* show that CDFDI has a significant promotion effect on economic scale and technological progress, but has a significant inhibition effect on industrial structure. At the same time, the estimated coefficients of economic scale and industrial structure are significantly positive, and the coefficient of technological progress is significantly negative. This suggests that the CDFDI increases the carbon emissions of the B&R countries through the scale effect, but reduces the carbon emissions of the B&R countries through the structural and technological effects. This is similar to the findings of Wang et al. (2022b), Wang and Duan (2023), Qiu et al. (2024), and Li and Wang (2025).

To ensure the stability of the above conduction effect test, the Sobel test and Bootstrap test are used to further verify whether the conduction effects of economic scale, industrial

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structure, and technological progress exist. The results show that the conduction effects of the above three mechanism variables are verified. Comparing the proportion of the three conduction effects in the total effect, it can be seen that the structural effect plays the largest role (21.73%), the scale effect plays the second largest role (accounting for 20.55%), and the technology effect plays the relatively smallest role (accounting for 20.08%).

To comprehensively analyze the scale, structural, and technological effects of China's CDFDI on the carbon emissions of the B&R countries. Let us look at the estimation results of the explanatory variables on the mechanism variables and the core explanatory variables, i.e., the regression results in columns (8), (10), and (12). The estimated coefficients of the *lnCDFDI* are significantly negative, both under the presence of the scale effect and in the presence of the structural and technological effects. This shows that economic scale, industrial structure, and technological progress have played a part in the role of the conduction effect and that China's CDFDI can inhibit the carbon emissions of the B&R countries by affecting these three conduction variables.

Testing the moderating effect of environmental regulations

Considering that environmental regulation may affect the relationship between CDFDI and carbon emissions. Based on the practice of scholars such as Chen (2023), this paper introduces the cross-multiplication term (*lnCDFDI* lnERI*) of the coordinated development of environmental regulation and two-way FDI, and constructs the following adjustment effect model based on the benchmark model, as shown in *Equation 29*:

$$\mathrm{lnCO}_{2_{jt}}=\beta_0+\beta_1\mathrm{lnCDFDI}_{jt}+\beta_2\mathrm{lnERI}_{jt}+\beta_3\mathrm{lnCDFDI}_{jt}*\mathrm{lnERI}_{jt}+\beta_4X_{jt}+\varepsilon_{jt} \quad \text{(Eq.29)}$$

In addition, to further test how environmental regulations change the mechanism of CDFDI on carbon emissions. Therefore, referring to Wen and Ye (2014), the transmission effect model with moderating variable (*lnERI*) is built and re-estimated as follows:

$$\mathrm{lnw}_{jt}=\delta_0+\delta_1\mathrm{lnCDFDI}_{jt}+\delta_2\mathrm{lnERI}_{jt}+\delta_3\mathrm{lnCDFDI}_{jt}*\mathrm{lnERI}_{jt}+\delta_4X_{jt}+\varepsilon_{jt} \quad \text{(Eq.30)}$$

$$\mathrm{lnCO}_{2_{jt}}=v_0+v_1\mathrm{lnCDFDI}_{jt}+v_2\mathrm{lnERI}_{jt}+v_3\mathrm{lnCDFDI}_{jt}*\mathrm{lnERI}_{jt}+\varphi\mathrm{lnw}_{jt}+v_4X_{jt}+\varepsilon_{jt} \quad \text{(Eq.31)}$$

where $lneri_{jt}$ is the moderating variable, representing the intensity of environmental regulations, its measurement method refers to the approaches of Li et al. (2022) and Chakrabartya and Mukherjeeb (2013), using the Environmental Performance Index (*EPI*) published by Yale University as the standard for measurement. In general, the larger the *EPI* value, the more effective the country's environmental pollution control is and the stricter the environmental regulatory standards are. Since *EPI* is only released in even-numbered years, this paper adopts the average value of *EPI* in two adjacent years to supplement its data in odd-numbered years. β_3 and δ_3 are parameters to be estimated, which represent the influence of the interaction term *(lnCDFDI*lnERI*) of the CDFDI and environmental regulation on carbon emissions and various transmission mechanism variables (economic scale, industrial structure, and technological progress), respectively. β_3 and v_3 represent the total effect and direct effect of the CDFDI on carbon emissions under environmental regulation. Φ represents the impact of each transmission

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mechanism variable on carbon emissions, that is, the indirect effect. The meaning of other variables is consistent with the previous text, and it is not repeated here. To alleviate collinearity, the cross-term is centralized. *Table 4* shows the regression results of environmental regulation as a moderating variable.

Table 4. *Test results of the regulatory effect of environmental regulations*

Variable	(13) $lnCO_2$	(14) lnSCALE	(15) $lnCO_2$	(16) STRUC	(17) $lnCO_2$	(18) lnTEC	(19) $lnCO_2$
lnCDFDI	-0.0532 (0.0334)	0.7419*** (0.0766)	-0.0840** (0.0349)	-0.0426 (0.0262)	-0.0311 (0.0322)	0.6725*** (0.0955)	-0.0727** (0.0329)
lnERI	-0.0888** (0.0357)	-0.0474 (0.0338)	-0.0869** (0.0361)	0.0003 (0.0158)	-0.0890*** (0.0331)	-0.1201 (0.0827)	-0.0742** (0.0348)
*lnCDFDI*lnERI*	-0.3191*** (0.0634)	-0.1693* (0.0922)	-0.3121*** (0.0634)	-0.0696** (0.0329)	-0.2831*** (0.0602)	0.3268** (0.1540)	-0.3066*** (0.0615)
lnSCALE			0.0416* (0.0214)				
STRUC					0.5173*** (0.0419)		
lnTEC							-0.0564*** (0.0085)
Control variable	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	8.2327*** (0.0058)	24.1665*** (0.0093)	7.2283*** (0.5177)	3.3079*** (0.0037)	6.5214*** (0.1384)	4.9130*** (0.0203)	7.9558*** (0.0421)
Observations	1463	1463	1463	1463	1463	1463	1463
R^2	0.9838	0.9543	0.9838	0.8539	0.9859	0.9102	0.9844

Collectively, the estimation results underscore a significantly negative coefficient for the *lnCDFDI*lnERI* interaction term (*Table 5,* column 13), indicating that environmental regulation acts as a positive moderating force in enhancing CDFDI's contribution to carbon emission reduction. This corroborates the work of Yue et al. (2024), which positions robust environmental regulations as a key factor in mitigating the carbon footprint of CDFDI.

Specifically, firstly, the regression results in column (14) show that the coefficient for (*lnCDFDI*lnERI)* is significantly negative, while the coefficient for economic scale (*lnSCALE*) in column (15) is significantly positive and smaller than the coefficient without environmental regulation (0.0416 < 0.0456). This indicates that under the moderating effect of environmental regulation, China's CDFDI mitigates the increase in carbon emissions among the B&R countries by reducing economic scale. A possible explanation is that regions with stricter environmental regulations may reduce foreign investors' willingness to invest, while outward investment tends to flow toward regions with weaker environmental regulations (Dean et al., 2009). Secondly, the results in column (16) show that the interaction term between CDFDI and environmental regulations (*lnCDFDI*lnERI*) has a negative coefficient that passes the 1% significance level test.

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This indicates that under environmental regulation, CDFDI is more conducive to reducing the share of industrial value-added in the Belt and Road partner countries, thereby optimizing their industrial structure. Concurrently, column (17) shows a significantly positive coefficient for industrial structure, suggesting that environmental regulation enhances the role of industrial structure in suppressing carbon emissions in the B&R partner countries. Thirdly, the regression results in column (18) show that the *lnCDFDI*lnERI* coefficient is significantly positive, indicating that the technology spillover effect of the CDFDI is further strengthened under the role of environmental regulation. This is similar to the findings of Zhang and Wu (2016) that the rise in the level of environmental regulation contributes to the improvement of FDI technology spillovers, and that different types of environmental regulation can effectively promote green technological innovation in the home country, although there are differences in the impact of green technology spillovers from OFDI. Meanwhile, the results in column (19) reveal a significantly negative coefficient for both *lnTEC* and its interaction term (at the 5% level), which implies that the environmental regulation strengthens the inhibiting effect of coordinated development of the technological spillover effect of two-way FDI on the carbon emission of the B&R countries.

Table 5. *Endogeneity discussion and robustness analysis*

Variable	Robustness analysis				Endogeneity discussion	
	Replacement of the core explanatory variables	**Replacement of explanatory variables**	**Have one's tail reduced**	**Adding control variables**	**2SLS**	**System GMM**
	(20)	**(21)**	**(22)**	**(23)**	**(24)**	**(25)**
L.CO_2						0.9613*** (0.0164)
lnCDFDI	-0.0981*** (0.0227)	-0.1845*** (0.0243)	-0.2132*** (0.0269)	-0.1075*** (0.0278)	-0.0497* (0.0291)	-0.0975*** (0.0264)
TRADE	0.0015*** (0.0005)	0.0006 (0.0005)	0.0012** (0.0005)	0.0004 (0.0004)	0.0020** (0.0010)	0.0019*** (0.0004)
K	0.0112*** (0.0012)	0.0072*** (0.0012)	0.0121*** (0.0013)	0.0099*** (0.0011)	0.0085*** (0.0026)	0.0053*** (0.0010)
RD	-0.0596 (0.1397)	-0.0449 (0.0277)	-0.0371 (0.0338)	-0.0750*** (0.0287)	0.3472 (0.3580)	0.1137*** (0.0207)
lnL	-0.0658** (0.0308)	-0.1520 (0.1330)	0.4191*** (0.1309)	-0.2075* (0.1207)	0.0118 (0.0722)	0.0859*** (0.0325)
lnDEN	1.1381*** (0.1586)	0.2689* (0.1504)	0.5500*** (0.1506)	0.9941*** (0.1311)	1.0884** (0.4344)	-0.0210 (0.0156)
lnURB				2.3010*** (0.1437)		
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes
F-value weak instrumental variable test					562.52 (0.0000)	
P-value for the over-identification test					16.13 (0.0133)	
AR (1)						0.000
AR (2)						0.960
Hansen J					0.147	0.341
Constant	3.5906** (1.6631)	1.5252 (1.5996)	-1.6347 (1.5672)	-2.7169* (1.4713)	— (1.1899)	-1.9514*** (0.3327)
Observations	1463	1463	1463	1463	1386	1386
R^2	0.9881	0.9857	0.9883	0.9908	0.4229	—

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To sum up, while hindering the inflow and outflow of two-way FDI in China, environmental regulations not only reduce the scale effect of the CDFDI, which slows down the increase in carbon emissions of the B&R countries, but they also optimize the structural allocation of two-way FDI and improve the quality of attracting foreign investment and outward investment, which in turn greatly enhances its structural and technological effects, which contributes to the reduction of carbon emissions of the B&R countries. It also optimizes the structural allocation of two-way direct investment and improves the quality of attracting foreign investment and outward investment, which in turn greatly enhances the structural and technological effects. This has contributed to the reduction of carbon emissions in the B&R countries. Therefore, in the future, we can appropriately raise the environmental regulation standards, without affecting the flow of capital and the layout of production and operation of enterprises, to drive the inflow and outflow of two-way FDI to be more in line with the green development goals of the B&R countries, and to further strengthen the inhibiting effect of China's CDFDI on the carbon emissions of the countries along the routes.

Discussion

Endogeneity discussion and robustness analysis

Considering the possible endogeneity between the core explanatory variable of *lnCDFDI* and the explanatory variable carbon emission ($lnCO_2$). Thus, this paper lags the core explanatory variable (*lnCDFDI*) by one period, which is proposed to be discussed by two-stage least squares and systematic GMM methods, and the results are shown in *Table 5*.

First, column (24) of *Table 5* reports the estimation results of the second stage of the two-stage least squares method. The statistic of the weak instrumental variable test is 562.52, which is greater than the Stock Yogo threshold for weak instrumental variables and passes the significance test at the 1% level. It indicates that there is no weak instrumental variable identification problem. Meanwhile, the over-identification test has a statistic of 16.13 and passes the test of significance at least at the 10% level, rejecting the original hypothesis that the instrumental variable is not identifiable. In addition, the regression results also show that the estimated coefficients of *lnCDFDI* are significantly negative at least at the 1% level. This indicates that after the endogeneity treatment, the CDFDI in China still significantly suppresses the carbon emissions of the B&R countries. Column (25) reports the estimation results of the systematic GMM method. Where the Hansen statistic is insignificant, indicating that there is no over-identification of instrumental variables. Meanwhile, the first-order autocorrelation is significant while the second-order autocorrelation is insignificant, indicating the existence of first-order residual autocorrelation but not second-order residual autocorrelation, which suggests that the selected instrumental variables are more reasonable. From the estimation results, the coefficient of the CDFDI is still significantly negative, indicating that the inhibiting effect of China's CDFDI on the carbon emissions of the B&R countries still exists after considering the endogeneity problem.

In addition, this section uses the methods of replacing the core explanatory variables and the explanatory variables, shrinking the tails before and after 1% of the variables, and adding control variables to conduct the robustness test and the regression results are shown in *Table 5*. The coefficient size and significance of the *lnCDFDI* in columns (21)-(23) did not change too much, which suggests that the results of this paper's benchmark regression are still robust.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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Discussion of heterogeneity

Considering that the carbon emission effect of CDFDI is affected by different countries, different stages, different infrastructure levels, and different levels of CDFDI, we further group the two-way FDI by country type, period, infrastructure level and CDFDI to examine the impact of CDFDI on the co-construction of the Belt and Road under different conditions. Therefore, it is further grouped according to country type, period, infrastructure level, and CDFDI level to examine the heterogeneity of the effect of China's CDFDI on carbon emissions of the B&R countries under different conditions, as shown in *Table 6*.

Table 6. *Heterogeneity regression results*

Variable	(26)	(27)	(28)	(29)	(30)	(31)	(32)	(33)
	Different countries		Different periods		Different levels of infrastructure		Level of CDFDI	
	Developed economy	Transition and developing economies	2003-2012	2013-2021	High	Low	High	Low
lnCDFDI	-0.0491***	-0.0046	-0.0152	-0.1120***	-0.0668**	0.0078	-0.2103***	0.2485
	(0.0106)	(0.0385)	(0.0102)	(0.0254)	(0.0299)	(0.0389)	(0.0321)	(0.1883)
TRADE	0.0011**	0.0037***	0.0012***	0.0047***	0.0005	0.0025***	0.0020***	0.0014*
	(0.0005)	(0.0006)	(0.0004)	(0.0008)	(0.0005)	(0.0006)	(0.0007)	(0.0008)
K	0.0085***	0.0088***	0.0083***	0.0043**	0.0066***	0.0089***	0.0025	0.0136***
	(0.0015)	(0.0013)	(0.0014)	(0.0022)	(0.0013)	(0.0014)	(0.0016)	(0.0017)
RD	-0.6142***	0.1411	0.2748*	0.6240**	0.3053	-0.0902	0.3467**	-0.2274
	(0.1724)	(0.1369)	(0.1666)	(0.2463)	(0.2465)	(0.1747)	(0.1642)	(0.1974)
lnL	-0.1104***	-0.0036	-0.0753***	-0.0949**	-0.0714**	0.0978***	0.0475*	-0.1317**
	(0.0333)	(0.0430)	(0.0281)	(0.0408)	(0.0345)	(0.0355)	(0.0267)	(0.0657)
lnDEN	0.7982***	0.5998***	0.5012**	1.0876***	0.1119	0.5770***	1.4561***	1.3633***
	(0.2110)	(0.1556)	(0.1974)	(0.3789)	(0.2521)	(0.2091)	(0.2303)	(0.2169)
Country fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Constant	13.5229***	3.0236*	1.5648	-4.2193	3.0781	6.5350***	-3.9654**	5.8653***
	(1.9020)	(1.6560)	(1.8911)	(2.9346)	(2.8069)	(2.2098)	(1.8832)	(2.0790)
Observations	380	1083	770	693	732	731	733	730
R^2	0.9941	0.9904	0.9962	0.9956	0.9949	0.9942	0.9947	0.9836

Regression results of different countries

This paper adheres to the official country classification standards of the 2021 International Monetary Fund (IMF) World Economic Outlook database. It categorizes the BRI countries into two broad groups, developed economies, transition economies, and developing economies, based on their level of economic development for heterogeneity analysis. As can be seen from *Table 6*, the estimated coefficient of *Equation 26* on the CDFDI is significantly negative, while the estimated coefficient of *Equation 27* is negative but not significant. This indicates that China's two-way FDI with developed economies along the Belt and Road effectively reduces the carbon emissions of the countries along the route. The reason is that developed countries have a good economic foundation and obvious advantages in low-carbon technology, and outward direct investment in them can help them learn their advanced environmental protection technology through reverse technology spillover, which also facilitates the developed

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economies to invest in China, and reduces their carbon emissions while improving the utilization of resources. The coordinated development level of two-way FDI between China and the transforming and developing economies of the Belt and Road has an insignificant inhibiting effect on carbon emissions, indicating that there is still much room for improvement.

Different stages of regression results

In 2013, after the BRI was put forward, China’s OFDI developed rapidly, and the development trend of two-way FDI became more and more obvious. Therefore, taking 2013 as the time node, the sample is divided into two stages of regression analysis: 2003-2012 and 2013-2021. As shown in column (28) of *Table 6*, the estimated coefficient of the CDFDI is negative but not significant from 2003 to 2012, which indicates that the level of CDFDI in China is low in this period, and therefore, its inhibitory effect on carbon emissions is insufficient. On the other hand, column (29) of *Table 6* shows that the estimated coefficient of the CDFDI is significantly negative, indicating that with the rapid growth of China’s outward foreign direct investment scale, the scale of FDI and OFDI is getting closer and closer to each other. Therefore, the level of CDFDI is getting higher and higher, which is conducive to the promotion of carbon emission reduction in the B&R countries.

Regression results of different infrastructure levels

This section analyses the heterogeneity of the countries along the Belt and Road according to the Internet penetration rate by dividing them into two groups of high and low infrastructure levels. From the regression results in *Table 6*, the estimated coefficients of *Equations 30* and *31* are -0.0681 and 0.0078, respectively, with the former passing the test at the 5% significance level and the latter failing the significance test. This suggests that China’s CDFDI can significantly reduce its carbon emissions when the infrastructure level of the B&R countries is high. However, when the infrastructure level of the B&R countries is low, China’s CDFDI does not have a significant impact on the carbon emissions of the regions along the routes. According to the absorptive capacity theory proposed by Cohen and Levinthal (1990), the carbon reduction effect of two-way FDI is not homogeneous; it largely depends on the host country’s infrastructure level. Countries with higher infrastructure levels possess greater capacity to absorb and disseminate the advanced green technologies embedded in two-way direct investment, thereby generating stronger carbon mitigation effects. Consequently, China’s CDFDI exerts a more pronounced carbon emission suppression effect on the B&R partner countries with higher infrastructure levels.

Regression results of different levels of CDFDI

Considering that there are high and low levels of CDFDI between China and the B&R countries, the sample is divided into high-level and low-level groups by taking the median level of CDFDI as the boundary. According to the regression results of models (32) and (33), the estimated coefficients of the CDFDI level of the higher group are significantly negative. That is, for every 1 percentage point increase in the coordinated development level of two-way FDI, the carbon emissions of the B&R countries will decrease by 0.2103 percentage points. When the level of CDFDI between China and the B&R countries is low, the estimated coefficient is not significant, which means that the CDFDI at this time

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cannot reduce the carbon emissions of the B&R countries. There may be two reasons for this: one is that a country's level of economic development serves as the foundation for its environmental technological progress (Grossman and Krueger, 1991). According to the theory of investment development paths, high levels of economic development are typically accompanied by high-quality two-way direct investment (Dunning, 1981). That is, countries with a high level of coordinated two-way FDI also tend to have relatively high levels of economic development. Consequently, these technologically advanced nations can effectively leverage green technology spillovers from two-way FDI to reduce carbon emissions. The second is that a high level of CDFDI correlates with a more balanced scale and structure between IFDI and OFDI. This balance facilitates progress in environmental technology (Gong and You, 2022), thereby creating the synergy necessary for substantial emission reduction along the B&R route. Consequently, significant carbon mitigation hinges on strong CDFDI between China and partner nations.

Conclusions, recommendations, and outlook

Conclusions of the study

This paper selects the data related to the two-way direct investment between China and the B&R countries as the research samples, constructs the theoretical model of the impact of the CDFDI on carbon emission from the three dimensions of scale effect, structural effect and technological effect, and establishes the fixed effect model, the conduction effect model and the regulating effect model, and empirically checks the carbon emission effect and its conduction path of CDFDI between China and the B&R countries. We also establish a fixed effect model, conduction effect model, and regulation effect model to empirically test the carbon emission effect and transmission path of China's CDFDI in the B&R countries. The main conclusions of the study are as follows:

As the level of China's CDFDI rises, the total carbon emissions of the B&R countries show a downward trend. (2) China's CDFDI reduces the carbon emissions of the B&R countries mainly through three channels: economic scale, industrial structure, and technological progress. Environmental regulation further strengthens the inhibiting effect of China's CDFDI on the carbon emissions of the Belt and Road Countries. That is to say, by weakening the impact of the CDFDI on economic growth, and strengthening the promotion of the CDFDI on industrial structure and technological progress, to reduce the carbon emissions of the B&R countries. (3) The impact of China's CDFDI on the carbon emissions of the B&R countries varies across different country types, periods, and infrastructure levels. China's CDFDI significantly reduces the carbon emissions of developed countries along the BRI. The suppressive impact of China's CDFDI on carbon emissions in countries along the route became statistically discernible only following the introduction of the BRI. A significant inhibitory effect of China's CDFDI on carbon emissions is observed exclusively in host countries with well-developed infrastructure. Carbon emissions in B&R countries are effectively reduced only when the intensity of CDFDI between China and these countries reaches a relatively high threshold.

Policy recommendations

Based on the above conclusions, this paper puts forward the following targeted recommendations: Firstly, the rational layout of China's two-way FDI flows, both high-quality "bringing in" and high-level "going out". At the same time, it is also necessary to

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link up IFDI and OFDI interaction channels and continuously improve China's CDFDI. Secondly, it is necessary to give full play to the scale, structural, and technological effects of China's two-way FDI. For example, it should reasonably plan the scale effect of China's two-way FDI, further optimize its energy consumption structure and industrial structure, and speed up the introduction of research and development of environmental protection technology and low-carbon technology. Thirdly, the implementation of differentiated two-way FDI policies to mitigate the adverse impact on carbon emissions in the B&R countries. For example, to further optimize the structure of China's two-way direct investment, while investing in developed countries along the Belt and Road in search of cleaner production technologies, it is also necessary to strengthen investment cooperation with developing countries in transition and along the Belt and Road. Fourthly, it is essential to design environmental regulations that are suited to the development contexts of the B&R countries and leverage their role fully. At the same time, leveraging two-way FDI as a bridge, we will guide the B&R countries to actively integrate into the global innovation network. This will enable local researchers and enterprises to access international knowledge flows, collaboration opportunities, and best practices, thereby enhancing the return on investment and attractiveness of future R&D investments in these regions.

Research gaps and outlook

On the one hand, influenced by the data, this paper only measures the coordinated development level of China's two-way FDI from the level of two-way FDI scale and has not yet considered the structure and quality of two-way FDI. At present, China emphasizes high-level opening up, continuously enhancing the quality and level of international investment cooperation, and proactively guiding such investments into sectors that form linkages and synergies with domestic industries. This approach will help elevate the R&D potential and innovation ecosystems of countries along the Belt and Road, thereby reducing carbon emissions. Therefore, in the future, the quality or structure of two-way FDI development can also be discussed from the perspective of its coordinated relationship in various aspects, to expand the depth of the existing research. On the other hand, the impact of foreign direct investment on carbon emissions is also influenced by a country's absorption capacity. Enhancing this capacity serves as a fundamental prerequisite for attracting more high-quality, innovative FDI and conducting more complex local R&D. Therefore, when examining the mechanism through which China's CDFDI affects carbon emissions, it is advisable to further consider the moderating effects of variables such as human capital, intellectual property protection, and innovation systems in the B&R countries.

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APPENDIX

Table A1. *List of countries covered by empirical analysis*

Country category	Specific country list
Developed economies (20)	Italy, Malta, Luxembourg, Greece, Portugal, Cyprus, Austria, Bulgaria, Croatia, the Czech Republic, Hungary, Israel, New Zealand, Poland, Romania, Estonia, Latvia, Lithuania, Slovakia, and Slovenia
Transition and developing economies (57)	Argentina, Indonesia, South Korea, Singapore, Malaysia, Kuwait, Russia, Thailand, Vietnam, Egypt, Mongolia, Iran, Ukraine, Iraq, Pakistan, the Philippines, Saudi Arabia, Armenia, South Africa, Sri Lanka, Panama, Turkey, Kazakhstan, Kyrgyzstan, Tajikistan, Belarus, Azerbaijan, Madagascar, Oman, Georgia, Qatar, Nepal, Brunei, Uzbekistan, Iran, Jordan, Algeria, Ethiopia, Ghana, Kenya, Morocco, Namibia, Sudan, Tunisia, Uganda, Zambia, Moldova, Serbia, Costa Rica, Cuba, Honduras, Peru, El Salvador, Venezuela, Uruguay, Mauritius, Chile

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