Review Article

The Impacts of Freight Trade on Carbon Emission Efficiency: Evidence from the Countries along the "Belt and Road"

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Extensive research has been carried out on the "Belt and Road" initiative, most of it focusing on geographical economy and international trade. However, there is a lack of research on the carbon emissions efficiency of the countries along the "Belt and Road," especially regarding the impact of freight trade. To address this research gap, this paper first employs a metafrontier nonradial directional distance function to measure the carbon emission efficiency of 32 countries along the "Belt and Road" from 1990 to 2014. It then examines the role of freight trade. Our main research findings are as follows. Firstly, the carbon emission efficiency of the countries along the "Belt and Road" is generally low. Among them, Russia and Central Asia are mainly due to the large between-group gap in carbon emission efficiency, while Southeast Asia, Western Asia and North Africa, East Asia, South Asia, and Central and Eastern Europe are mainly due to the large within-group gap. Secondly, freight trade promotes carbon emission efficiency, but it will aggravate the gap between the contemporaneous technology and the group technology. Freight trade mainly promotes the contemporaneous carbon emission efficiency (CTCEI) and group-frontier carbon emission efficiency (ITCEI) of low fossil energy dependent countries, and the metafrontier carbon emission efficiency (GTCEI) of high fossil energy dependent countries. Thirdly, foreign direct investment (FDI) has a significant negative effect on a host country's ITCEI and GTCEI, and it will decrease the gap between the group technology and the metafrontier technology. However, freight trade can effectively prevent the entry of FDI, thereby indirectly improving carbon emission efficiency and reducing carbon emission gap.

1. Introduction

Since the Chinese government puts forward the major initiatives of the "Silk Road Economic Belt" and the "21st Century Maritime Silk Road" ("Belt and Road"), the economic and trade relations between the countries along the "Belt and Road" have entered a new phase of comprehensive and rapid development. According to the "Belt and Road" trade cooperation big data report, in 2017, the foreign trade volume of the 71 countries along the "Belt and Road" route was US $ 9.3 trillion, accounting for 27.8% of the total global trade. However, booming freight trade also leads to serious environmental pollution. According to the 2018 Global Environmental Performance Index (EPI) Report, the carbon dioxide emissions of countries along the "Belt and Road" account for nearly 50% of the total global carbon dioxide emissions. Under the trend of continuous strengthening of green barriers, accurately assessing the impact of freight trade on the carbon emission efficiency of various countries is not only conducive to a more reasonable allocation of the carbon emission responsibilities of each country but also can provide a scientific basis for various countries to adjust the import and export structure and promote a low-carbon economic growth model.

It is generally believed that a sound transportation infrastructure is conducive to international trade by reducing transaction costs among regions [1]. And scholars

have gradually paid more and more attention to the theoretical relationship between transportation and carbon emissions [2, 3]. Some scholars have shown that traffic volume and transportation structure are the main factors affecting transportation carbon emissions [4]. However, after considering the heterogeneity of transportation structure, it is found that, under the same conditions, the increased carbon emissions of freight transportation are significantly higher than the increase of passenger transportation [5]. Also, the carbon emission efficiency of railway transportation is better than that of private use of cars [6]. With the diversification of transportation means and the convenience of transportation infrastructure, the introduction of environmental protection policies and the use of low-carbon transportation are increasingly important to reduce carbon emissions [7–9]. It should be noted that transportation infrastructures exhibit inherent characteristics of networking and spatial spillover effects (spillover effect refers to an organization that not only produces the expected effect of the activity but also affects people or society outside the organization) [10]. Therefore, different spatial and temporal contexts will have a differentiated spatial spillover effect on carbon emissions [11].

Research on the impact of transportation on carbon emissions has begun to emerge. Studies have shown that transportation infrastructure will indirectly affect carbon emissions by affecting trade flows [12–14]. Peters [15] examined the input-output data of 87 countries in 2001 and found that international trade increased a host country's carbon emission intensity. Similarly, Wang et al. [16] analyzed the carbon emissions transfer patterns of 140 countries and regions around the world. They found a difference in the role and status of international carbon transfer between developed and developing countries at the global level. Ertugrul et al. [17] found that trade liberalization has increased carbon emissions in Turkey, India, China, and Indonesia. That is, these countries have become "pollution refuges" for developed countries, which have shifted carbon emissions through international trade. Wang et al. [18] estimated and analyzed the carbon emissions reflected in the Sino-Australian trade from 2000 to 2014. They argued that China's net carbon outflows from Australia should be considered as part of the international transfer of environmental load. Sánchez-Chóliz [19] demonstrated that Spain's implied carbon emissions in imports and exports account for 36% and 37% of total emissions, respectively. Steininger et al. [20] not only calculated Austria's final consumption and imported carbon transfer and sectoral contributions but also compared carbon emissions from a production perspective. Sun et al. [21] analyzed the CO_2 emissions reflected in Russia's international trade from 1995 to 2014 based on an input-output method and found that Russia is a net exporter of carbon dioxide. Based on these existing studies, we can conclude that international trade has triggered a spatial shift in carbon emissions, which has a wide-ranging and long-term impact on the total global carbon emissions and spatial pattern.

Therefore, with the continuous advancement of the "Belt and Road" initiative, will the increasingly frequent freight trade among countries result in carbon leakage and reduced carbon emission efficiency? Furthermore, there are economic, cultural, and geographical differences among countries, which lead to a different production frontiers for each country or decision-making unit (DMU). If all DMUs are used as a whole to measure carbon emissions efficiency, the result may be biased. Therefore, considering the heterogeneity of regional technological frontiers, how to accurately measure the carbon emission efficiency of countries along the "Belt and Road"? In addition, how will freight trade affect a country's carbon emission efficiency? Answering these questions can help these countries more rationally define their carbon emission responsibilities and achieve a win-win situation between carbon reduction and trade development.

Compared with existing studies, this paper's contribution areas are as follows. Firstly, the existing research on the carbon emissions of the countries along the "Belt and Road" due to transportation mainly concentrated on individual countries. As a result, the research results obtained in the literature cannot well reflect the overall situation of the countries along the "Belt and Road." And there is a lack of cross-national sample research. Chandran and Tang [22] suggested that economic growth and transportation energy consumption significantly impact long-term carbon dioxide emissions, while FDI has no effect on the carbon dioxide emissions of ASEAN countries. Similarly, in terms of low-carbon transportation development, Bakker et al. [23] analyzed the approaches and current status of sustainable low-carbon transportation policies in ASEAN countries. Danish et al. [24] used Pakistan's urban transport sector data to study the relationships among transport energy consumption, economic growth, foreign direct investment, and carbon dioxide emissions. This paper uses 32 countries along the "Belt and Road" as research samples from 1990 to 2014 to examine the impact of freight trade on a host country's carbon emissions efficiency. Our results show that freight trade is conducive to improving carbon emission efficiency. However, at the same time, it will aggravate the carbon emission efficiency gap between groups. Freight trade mainly promotes the current and intertemporal carbon emission efficiency of low fossil energy dependent countries and the global carbon emission efficiency of high fossil energy dependent countries.

Secondly, different from the methods to evaluate carbon emission efficiency in the literature, this paper builds a new total factor carbon emission productivity model based on a metafrontier nonradial directional distance function. Our results show that the carbon emission efficiency of countries along the "Belt and Road" is generally low. Among them, Russia and Central Asia are mainly due to the excessive gap in carbon emission efficiency between the groups, while the remaining five regions (Southeast Asia, West Asia and North Africa, East Asia, South Asia, and Central and Eastern Europe) are

mainly due to the excessive gap in carbon emission efficiency within the group.

Thirdly, there has been no research combining trade and FDI into the same framework to explore their joint impacts on carbon emission efficiency. In fact, foreign trade and FDI may be complementary or substitutional, which indirectly affects environmental pollution. Hence, this paper incorporates FDI as an intermediary variable and constructs an intermediary effect model. Our empirical analysis and results show that FDI can significantly inhibit a host country's intertemporal and overall carbon emission efficiency. This would increase the carbon emission efficiency gap between the groups.

The rest of the paper is organized as follows. Section 2 presents and improves a measurement method of carbon emission efficiency. It then presents the empirical model in details. Section 3 introduces related data and variables. Section 4 presents our empirical analysis and results. The conclusions and policy implications are summarized in Section 5.

2. Method

2.1. Metafrontier and Nonradial Directional Distance Function. This paper takes each country as a DMU to construct the production frontier. Each DMU uses labor (L), capital (K), and energy (E) as inputs and its outputs are production expected output (Y) and undesired output CO_2

(C). The production technology set T is determined as follows:

$$T = \{(K, L, Y, C): \ (K, L, E) \text{ can produce } (Y, C)\}. \tag{1}$$

According to Färe et al. [25], the production technology set should meet the following properties in addition to satisfying the closed sets and bounded sets:

(1) Inputs are strongly disposable, namely, if $(K, L, E, Y, C) \in T$ and $(K', L', E', Y', C') < (K, L, E, Y, C)$, then $(K', L', E', Y', C') \in T$.

(2) Desirable outputs disposable, namely, if $(K, L, E, Y, C) \in T$ and $(Y', C) < (Y, C)$, then $(K, L, E, Y', C) \in T$.

(3) Outputs are jointly and weakly disposable, namely, if $(K, L, E, Y, C) \in T$ and $0 \leq \theta \leq 1$, then $(K, L, E, \theta Y, \theta C) \in T$. This means that the production of expected output will inevitably produce unintended output and thus reducing unintended output will inevitably sacrifice expected output.

(4) Outputs have null-jointness, namely, $(K, L, E, Y, C) \in T$ and $C = 0$, then $Y = 0$. This means that desirable output cannot be achieved without undesirable output.

Based on the properties above, the technological set containing undesired outputs can be expressed as follows:

$$T = \left\{(K, L, E, Y, C): \ \sum_{n=1}^{N} \lambda_n K_n \leq K; \ \sum_{n=1}^{N} \lambda_n E_n \leq E; \ \sum_{n=1}^{N} \lambda_n Y_n \leq Y; \ \sum_{n=1}^{N} \lambda_n C_n = C, n = 1, 2, \ldots, N \right\}, \tag{2}$$

where λ_n is the weight of each cross-section. If $\lambda_n \geq 0$, $\sum_{n=1}^{N} \lambda_n = 1$, it means that the variable scale return (VRS), otherwise constant scale return. In order to measure the carbon emission efficiency of each decision unit, we follow Zhang et al. [26] and construct a nonradial directional distance function:

$$\overrightarrow{D}(K, L, E, Y, C; g)$$
$$= \sup\{w^T \beta: \ [(K, L, E, Y, C) + g * \text{diag}(\beta)] \in T\}, \tag{3}$$

where $w^T = (w_K, w_L, w_E, w_Y, w_C)$ represents the standardized weight vector. As there are three input variables, one desirable output, and one undesirable output, we set w^T $(1/9, t1/9n, q1/9h_{1/3x}, 71/3)$. $g = (-g_K, -g_L, -g_E, -g_Y, -g_C)$ represents the direction vector, which is set as $g = (-K, -L, -E, -Y, -C)$. $\beta = (\beta_K, \beta_L, \beta_L, \beta_Y, \beta_C) \geq 0$ indicates the relaxation vector, which needs to be obtained by solving the following linear program:

$$\overrightarrow{D}(K, L, E, Y, C; g) = \max \frac{\beta_K}{9} + \frac{\beta_L}{9} + \frac{\beta_E}{9} + \frac{\beta_Y}{3} + \frac{\beta_C}{3}$$

$$s.t. \ \sum_{n=1}^{N} \lambda_n K_n \leq (1 - \beta_K)K$$

$$\sum_{n=1}^{N} \lambda_n L_n \leq (1 - \beta_L)L$$

$$\sum_{n=1}^{N} \lambda_n E_n \leq (1 - \beta_E)E \tag{4}$$

$$\sum_{n=1}^{N} \lambda_n Y_n \leq (1 - \beta_Y)Y$$

$$\sum_{n=1}^{N} \lambda_n C_n \leq (1 - \beta_C)C$$

$$\lambda_n \geq 0, \ n = 1, 2, \ldots, N$$

$$\beta_Y \geq 0, 0 \leq \beta_K, \beta_L, \beta_E, \beta_C < 1.$$

According to Zhou et al. [27] and Cheng et al. [28], the total factor carbon emission efficiency index (TCEI) can be expressed as follows:

$$\text{TCEI} = \frac{C - \beta_c C/(Y + \beta_Y Y)}{C/Y} = \frac{(1 - \beta_C)}{(1 + \beta_Y)}. \quad (5)$$

However, the calculation of the TCEI above is based on the fact that all DMUs have similar production technologies and face the same production frontier, without considering the technology gap between different DMUs. This may be biased. To overcome it, we follow Battese et al. [29] and O'Donnell et al. [30] and construct three frontiers of the contemporaneous technology sets, the intertemporal technology sets, and the metafrontier technology set.

Firstly, we classify all DMUs into H groups. The group h has N^h DMUs and $\sum_{h=1}^{H} N^h = N$. The input and output combinations of all DMUs in each group belong to the same production technology set R_h:

$$T_{R_h}^{C} = \left\{ \left(K^t, L^t, E^t, Y^t, C^t \right) : \left(K^t, L^t, E^t \right) \text{can produce} \left(Y^t, C^t \right) \right\}, \quad (6)$$

where $T_{R_h}^{C}$ only contains all the DMUs of group R_h in period t. Furthermore, the intertemporal environmental technology set of groups R_h can be defined as $T_{R_h}^{I} = T_{R_h}^{1} \cup T_{R_h}^{2} \cup \cdots T_{R_h}^{T}$. This set contains all the DMUs of group R_h at all times. The global environmental technology set can be defined as $T^{G} = T_{R_1}^{I} \cup T_{R_2}^{I} \cup \cdots T_{R_H}^{I}$ and contains all the DMUs of all groups at all times. Based on (4), we then construct the following contemporaneous NDFF:

$$\overrightarrow{D}^{C}\left(K, L, E, Y, C; g^C \right) = \max \frac{\beta_K^C}{9} + \frac{\beta_L^C}{9} + \frac{\beta_E^C}{9} + \frac{\beta_Y^C}{3} + \frac{\beta_C^C}{3}$$

$$s.t. \sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_K^C \right) K$$

$$\sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_L^C \right) L$$

$$\sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 + \beta_E^C \right) E$$

$$\sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_Y^C \right) Y \quad (7)$$

$$\sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_C^C \right) C$$

$$\lambda_n^t \ge 0, n = 1, 2, \ldots, N^h$$

$$\beta_Y^C \ge 0, 0 \le \beta_K^C, \beta_L^C, \beta_E^C, \beta_C^C < 1.$$

According to (5), the contemporaneous-frontier total-factor carbon emission efficiency index (CTCEI) can be defined as follows:

$$\text{CTCEI} = \frac{\left(1 - \beta_C^C \right)}{\left(1 + \beta_Y^C \right)}. \quad (8)$$

We then construct the following group NDFF:

$$\overrightarrow{D}^{C}\left(K, L, E, Y, C; g^C \right) = \max \frac{\beta_K^I}{9} + \frac{\beta_L^I}{9} + \frac{\beta_E^I}{9} + \frac{\beta_Y^I}{3} + \frac{\beta_C^I}{3}$$

$$s.t. \sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_K^C \right)\left(1 - \beta_K^I \right) K$$

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t L_n^t \le \left(1 - \beta_L^C \right)\left(1 - \beta_L^I \right) L$$

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t E_n^t \le \left(1 - \beta_E^C \right)\left(1 - \beta_E^I \right) E$$

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t Y_n^t \le \left(1 - \beta_Y^C \right)\left(1 - \beta_Y^I \right) Y$$

$$\sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t C_n^t \le \left(1 - \beta_C^C \right)\left(1 - \beta_C^I \right) C$$

$$\lambda_n^t \ge 0, t = 1, 2, \ldots, T, n = 1, 2, \ldots, N^h$$

$$\beta_Y^I \ge 0, 0 \le \beta_K^I, \beta_L^I, \beta_E^I, \beta_C^I < 1. \quad (9)$$

The group-frontier total-factor carbon emission efficiency index (ITCEI) can be defined as follows:

$$\text{ITECI} = \frac{\left(1 - \beta_C^C \right)\left(1 - \beta_C^I \right)}{\left(1 + \beta_Y^C \right)\left(1 + \beta_Y^I \right)}. \quad (10)$$

Similarly, we construct the following global NDFF:

$$\overrightarrow{D}^{C}\left(K, L, E, Y, C; g^C \right)$$

$$= \max \frac{\beta_K^G}{9} + \frac{\beta_L^G}{9} + \frac{\beta_E^G}{9} + \frac{\beta_Y^G}{3} + \frac{\beta_C^G}{3}$$

$$s.t. \sum_{h=1}^{H} \sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t K_n^t \le \left(1 - \beta_K^C \right)\left(1 - \beta_K^I \right)\left(1 - \beta_K^G \right) K$$

$$\sum_{h=1}^{H} \sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t L_n^t \le \left(1 - \beta_L^C \right)\left(1 - \beta_L^I \right)\left(1 - \beta_L^G \right) L$$

$$\sum_{h=1}^{H} \sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t E_n^t \le \left(1 - \beta_E^C \right)\left(1 - \beta_E^I \right)\left(1 - \beta_E^G \right) E$$

$$\sum_{h=1}^{H} \sum_{t=1}^{T} \sum_{n=1}^{N} \lambda_n^t C_n^t \le \left(1 - \beta_C^C \right)\left(1 - \beta_C^I \right)\left(1 - \beta_C^G \right) C$$

$$\lambda_n^t \ge 0, t = 1, 2, \ldots, T, n = 1, 2, \cdots, N^h, h = 1, 2, \ldots, H$$

$$\beta_Y^G \ge 0, 0 \le \beta_K^G, \beta_L^G, \beta_E^G, \beta_C^G < 1. \quad (11)$$

Then, the metafrontier total-factor carbon emission efficiency (GTCEI) can be defined as follows:

$$\text{GTCEI} = \frac{\left(1 - \beta_C^C\right)\left(1 - \beta_C^I\right)\left(1 - \beta_C^G\right)}{\left(1 + \beta_Y^C\right) + \left(1 + \beta_Y^I\right) + \left(1 + \beta_Y^G\right)}. \tag{12}$$

Following Oh [31] and Zhang and Choi [32], GTCEI can be decomposed as

$$\text{GTCEI} = \text{CTCEI} \times \frac{\text{ITCEI}}{\text{CTCEI}} \times \frac{\text{GTCEI}}{\text{ITCEU}} = \text{TE} \times \text{BPR} \times \text{TGR}, \tag{13}$$

where TE denotes the contemporaneous technological efficiency. $\text{BPR} \in [0, 1]$ denotes the ratio of ITCEI to CTCEI and reflects the gap between the contemporaneous technology and the group technology, and bigger BPR indicates that the gap between the contemporaneous technology and the group technology is closer. $\text{TGR} \in [0, 1]$ denotes the technical gap ratio. It reflects the gap between the group technology and the metafrontier technology, and bigger TGR indicates that the gap between the group technology and the metafrontier technology is closer.

2.2. Empirical Model.

In order to examine the impact of freight trade on a host country's carbon emission efficiency, this paper builds the following benchmark model:

$$\begin{cases} \text{LCTCEI}_{i,t} = \alpha_0^1 + \beta^1 \cdot \text{LIFT}_{i,t} + \gamma^1 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^1, \\ \text{LCTCEI}_{i,t} = \alpha_0^2 + \beta^2 \cdot \text{LIFT}_{i,t} + \gamma^2 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^2, \\ \text{LGTCEI}_{i,t} = \alpha_0^3 + \beta^3 \cdot \text{LIFT}_{i,t} + \gamma^3 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^3, \\ \text{LBPR}_{i,t} = \alpha_0^4 + \beta^4 \cdot \text{LIFT}_{i,t} + \gamma^4 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^4, \\ \text{LTGR}_{i,t} = \alpha_0^5 + \beta^5 \cdot \text{LIFT}_{i,t} + \gamma^5 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^5, \end{cases} \tag{14}$$

where LCTCEI, LITCEI, LGTCEI, LBPR, and LTGR denote the contemporaneous carbon emission efficiency, group-frontier carbon emission efficiency, metafrontier carbon emission efficiency, carbon emission efficiency gap within the group, and carbon emission efficiency gap between groups, respectively. LIFT denotes the freight trade variable, control is control variable. u_h, v_t, and $\varepsilon_{i,t}^j$ denote group and time fixed effect and residual, respectively. i is the ith country, t is the period, and L is the natural logarithm after adding 1 to all variables.

In order to further explore the specific path of the impact of freight trade on the carbon emission efficiency of a host country, we construct the following:

$$\begin{cases} \text{LCTCEI}_{i,t} = \alpha_0^1 + \beta^1 \cdot \text{LIFT}_{i,t} + \delta^1 \cdot \text{LFDI}_{i,t} + \gamma^1 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^1, \\ \text{LCTCEI}_{i,t} = \alpha_0^2 + \beta^2 \cdot \text{LIFT}_{i,t} + \delta^2 \cdot \text{LFDI}_{i,t} + \gamma^2 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^2, \\ \text{LGTCEI}_{i,t} = \alpha_0^3 + \beta^3 \cdot \text{LIFT}_{i,t} + \delta^3 \cdot \text{LFDI}_{i,t} + \gamma^3 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^3, \\ \text{LBPR}_{i,t} = \alpha_0^4 + \beta^4 \cdot \text{LIFT}_{i,t} + \delta^4 \cdot \text{LFDI}_{i,t} + \gamma^4 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^4, \\ \text{LTGR}_{i,t} = \alpha_0^5 + \beta^5 \cdot \text{LIFT}_{i,t} + \delta^5 \cdot \text{LFDI}_{i,t} + \gamma^5 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^5, \\ \text{LFDI}_{i,t} = \alpha_0^6 + \beta^6 \cdot \text{LIFT}_{i,t} + \gamma^6 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^6, \end{cases} \tag{15}$$

where LFDI denotes intermediary variable, which is the level of foreign investment attracted by the country in that year. In addition, in order to avoid the endogenousness caused by the reverse influence and missing variables to bias the results, this paper incorporates the first-order lag of the dependent variable into the regression equation to build a dynamic panel model:

$$\begin{cases} \text{LCTCEI}_{i,t} = \alpha_0^1 + \beta^1 \cdot \text{LIFT}_{i,t} + \delta^1 \cdot \text{LFDI}_{i,t} + \gamma^1 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^1, \\ \text{LCTCEI}_{i,t} = \alpha_0^2 + \beta^2 \cdot \text{LIFT}_{i,t} + \delta^2 \cdot \text{LFDI}_{i,t} + \gamma^2 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^2, \\ \text{LGTCEI}_{i,t} = \alpha_0^3 + \beta^3 \cdot \text{LIFT}_{i,t} + \delta^3 \cdot \text{LFDI}_{i,t} + \gamma^3 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^3, \\ \text{LBPR}_{i,t} = \alpha_0^4 + \beta^4 \cdot \text{LIFT}_{i,t} + \delta^4 \cdot \text{LFDI}_{i,t} + \gamma^4 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^4, \\ \text{LTGR}_{i,t} = \alpha_0^5 + \beta^5 \cdot \text{LIFT}_{i,t} + \delta^5 \cdot \text{LFDI}_{i,t} + \gamma^5 \cdot \text{Control}_{i,t} + u_i + v_t + \varepsilon_{i,t}^5, \\ \text{LFDI}_{i,t} = \alpha_0^6 + \beta^6 \cdot \text{LIFT}_{i,t} + \gamma^6 \cdot \text{Control}_{i,t} + u_h + v_t + \varepsilon_{i,t}^6. \end{cases} \quad (16)$$

3. Data and Variable

3.1. Data Source. There are 70 countries along the "Belt and Road." Due to the availability of relevant data and the fact that the dataset for measuring carbon emission efficiency needs to be balanced panel data, this paper selected the dataset of 32 countries from 1990 to 2014 as the research samples. In addition, this paper divides all the samples into seven groups according to the region, namely, Southeast Asia, East Asia, Russia, South Asia, West Asia and North Africa, Central and Eastern Europe, and Central Asia. The data used in this paper comes from *World Bank Development Indicators (WDI)*. The country names, abbreviations, and groupings are listed in Table 1.

3.2. Variable and Definition

(1) Input and output variables: this paper takes the GDP of each country as the desired output variable, CO_2 as the undesired output, the average annual employment as labor input, and the total energy consumption as energy input. Most of the existing studies use the perpetual inventory method to measure the current capital stock, but this method requires high data quality. Considering the data availability and quality, this paper follows Zhao et al. [33] and Hu et al. [34] and uses capital formation to express capital investment.

(2) Empirical variables: this paper takes the natural logarithm of LCTCEI, LITCEI, LGTCEI, LBPR, and LTGR plus 1 as the dependent variable and takes the natural logarithm after adding 1 to the ratio of the total import and export volume to the current year's freight volume (air freight volume and rail transport volume). As for the core independent variable representing the level of freight trade, we take the natural logarithm of the ratio of FDI stock to GDP in that year plus 1 as the intermediary variable. Control variables include government expenditure intensity (LRED), fossil energy dependence (LRFE), innovation level (LPatent), and industrialization level (LRID). More detailed variable settings and descriptions are shown in Table 2.

3.3. Descriptive Statistics. Table 3 shows the descriptive statistics of variables. The countries along the "Belt and Road" differ greatly in terms of input and output. This means that if a traditional DEA method is adopted, the measurement results will be greatly affected by the extreme value, resulting in bias. It is worth noting that the maximum value of fossil energy dependence is 0.1185. According to the formula exp (0.1185) −1, the dependence of fossil energy is 12.58%, indicating that the countries along the "Belt and Road" rely less on fossil energy.

4. Empirical Result

4.1. Carbon Emission Efficiency Calculation Results. Based on the methods and data described above, the carbon emission efficiency was measured. The results showed that the average values of CTCEI, ITCEI, and GTCEI gradually decreased to 0.793, 0.436, and 0.325, respectively, and the difference in efficiency between the groups was higher than that within the group, the average values of BPR and TCR were, respectively, 0.549 and 0.785.

Figure 1 shows the carbon emission efficiency and its decomposition from 1990 to 2014, where the left picture shows CTCEI, ITCEI, and GTCEI, and the right picture shows BPR and TGP. As can be seen from the graph on the left, CTCEI, ITCEI, and GTCEI all show a growth trend, indicating that countries along the "Belt and Road" have increased their carbon emission efficiency year by year. Although GTCEI and ITCEI are significantly smaller than CTCEI, it indicates that the carbon emission efficiency measured by traditional nonparametric methods will be significantly overestimated. As can be seen from the graph on the right, BPR is increasing year by year and at a faster rate, while TGP is showing a slow decline, which indicates that the carbon emission efficiency gap within each group is shrinking year by year, and the gap between each group has a trend of expanding year by year.

Figure 2 shows the average carbon emission efficiency by country and its decomposition. The left picture shows CTCEI, ITCEI, and GTCEI, and the right picture shows BPR and TGP. In the figure on the left, 13 countries (JPN, KAZ, Rus, POL, PAK, LKA, ISR, PHL, TUR, SVN, SGP, MYS, and HRV) have a CTCEI of 1, accounting for 40.63%, indicating that, for the vast majority of countries, the contemporaneous carbon emission efficiency has not reached the optimal level. The countries with the highest ITCEI and GTCEI are Japan (JPN) 0.7713 and the lowest are Belarus (BLR) 0.1610 and 0.1091, respectively, indicating that the intertemporal and metafrontier carbon emission efficiency is insufficient for all countries. In the figure on the right, except for LKA, TUR, KAZ, POL, and RUS, the TGP of all other countries is

TABLE 1: Country names and abbreviations.

Group	Abbreviation	Name	Group	Abbreviation	Name
Southeast Asia	MYS	Malaysia		ALB	Albania
	PHL	Philippines		BGR	Bulgaria
	SGP	Singapore		BLR	Belarus
	THA	Thailand		CZE	Czech Republic
	CHN	China		EST	Estonia
East Asia	JPN	Japan		HRV	Croatia
	KOR	Korea		HUN	Hungary
Russia	Rus	Russia	Central and Eastern	LTU	Lithuania
South Asia	LKA	Sri Lanka	Europe	LVA	Latvia
	PAK	Pakistan		MDA	Moldova
	ARM	Armenia		MKD	The former Yugoslav Republic of Macedonia
West Asia and North Africa	AZE	Azerbaijan		POL	Poland
	EGY	Egypt		ROU	Romania
	ISR	Israel		SVK	Slovakia
	SAU	Saudi Arabia		SVN	Slovenia
	TUR	Turkey	Central Asia	KAZ	Kazakhstan

TABLE 2: Variable and definition.

Variable	Name	Definitions
Desired output	GDP	GDP of each country, converted to GDP calculated at the 1990 price using the GDP deflator
Undesired output	CO_2	CO_2 published by the World Bank
Input variable	Capital	Capital formation, converted to capital at 1990 prices using PPI
	Labor	Average annual employment
	Energy	Total energy consumption
Dependent variable	LCTCEI	Take natural logarithm after adding 1 to CTCEI
	LITCEI	Take natural logarithm after adding 1 to ITCEI
	LGTCEI	Take natural logarithm after adding 1 to GTCEI
	LBPR	Take natural logarithm after adding 1 to BPR
	LTGR	Take natural logarithm after adding 1 to TGR
Core Variable	LIFT	Take the natural logarithm after adding 1 to the ratio of total import and export volume to the current year's freight volume (air freight volume and rail traffic volume)
Intermediary variable	LFDI	Take the natural logarithm after adding 1 to the ratio of FDI stock to GDP that year
Control variable	LRED	Take the natural logarithm after adding 1 to the ratio of government expenditure to GDP
	LRFE	The ratio of the fossil energy consumption (coal, oil and natural gas) to the total energy consumption is increased by 1 to take the natural logarithm
	LPatent	Take the natural logarithm after adding 1 to the ratio of the total number of patent applications to the number of employees in that year
	LRID	Take the natural logarithm after adding 1 to the ratio of industrial added value to GDP

TABLE 3: Descriptive statistics of variables.

| Variable	N	Mean	St. Dev.	Min	Median	Max
GDP	800	376952.6	1109152	1170.191	62797.23	10534527
CO_2	800	350200.2	1075537	1543.807	61985.13	10291927
Labor	800	34761	124804.4	2	4683.2	772500
Capital	800	114810.1	406878.3	640.3	15277.35	4927496
Energy	800	2409.021	1458.53	322.9993	2361.099	7370.653
LIFT	800	2.176	1.4626	0.1233	2.1045	4.7775
LFDI	800	0.2089	0.1599	0.0131	0.1647	0.5664
LRED	800	0.1479	0.0419	0.0836	0.1523	0.2227
LRFE	800	0.0274	0.0351	0.0000	0.0086	0.1185
LPatent	800	0.378	0.4784	0.0252	0.1826	1.8142
LRID	800	3.5177	0.2358	2.906	3.5346	3.8991
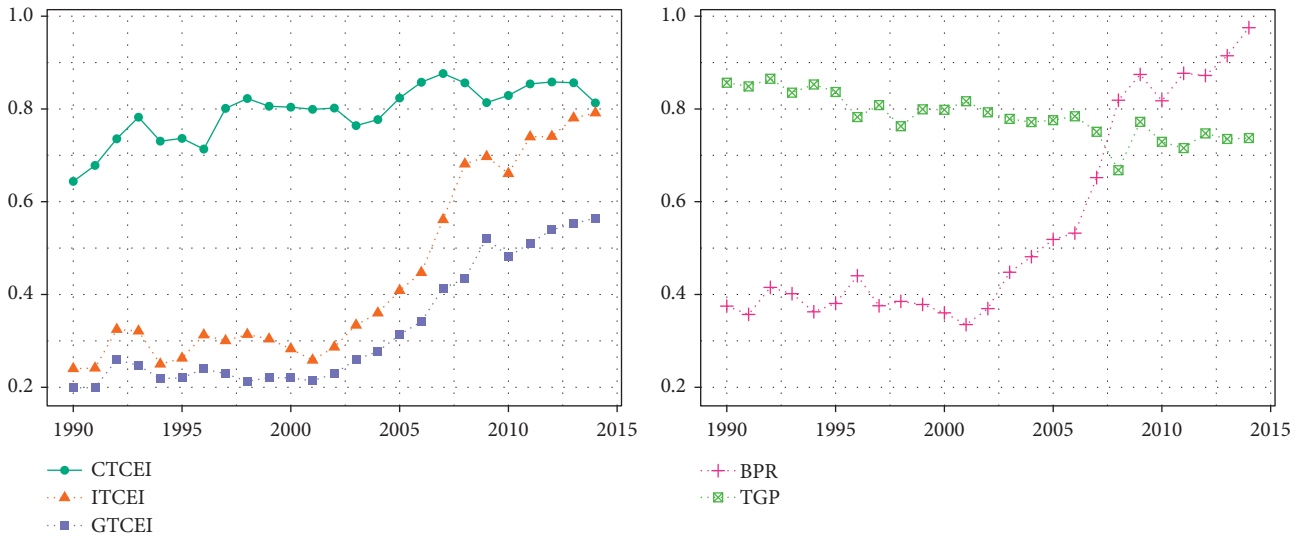
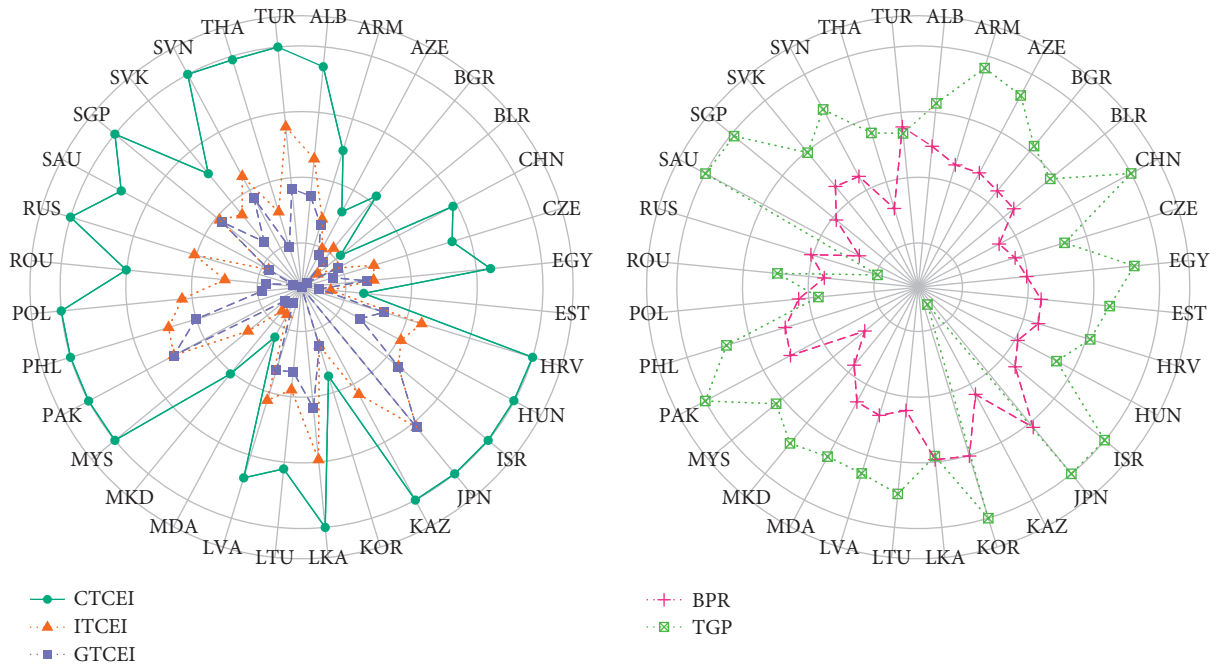FIGURE 1: Carbon emission efficiency and its decomposition in 1990–2014.

FIGURE 2: Average carbon emission efficiency by country and its decomposition.

greater than BPR, indicating that, for most countries, the gap in carbon emission efficiency within the group is the main reason for hindering the improvement of carbon emission efficiency.

In order to further explore the differences between the regions along the "Belt and Road," this paper divides all countries into seven groups (Southeast Asia, East Asia, Russia, South Asia, West Asia and North Africa, Central and Eastern Europe, and Central Asia) and describes their carbon emission efficiency. The change trend is shown in Figures 3–5.

Figure 3 shows the average annual carbon emission efficiency per group. The upper-left picture shows CTCEI,

the upper-right picture shows ITCEI, and the lower-left picture shows GTCEI. In the upper-left graph, except for East Asia, West Asia, North Africa, and Central and Eastern Europe, the CTCEI of other regions is 1, indicating that the contemporaneous carbon emission efficiency of these regions is at an optimal level. In the upper-right picture, ITCEI is less than 1 in most years in most regions except Russia and Central Asia, and GTCEI has a similar situation, as shown in the lower-left picture. This shows that the "Belt and Road" countries have long faced insufficient group-frontier carbon emission efficiency and metafrontier carbon emission efficiency. However, it is worth noting that ITCEI and GTCEI have always maintained a growth trend, indicating that the

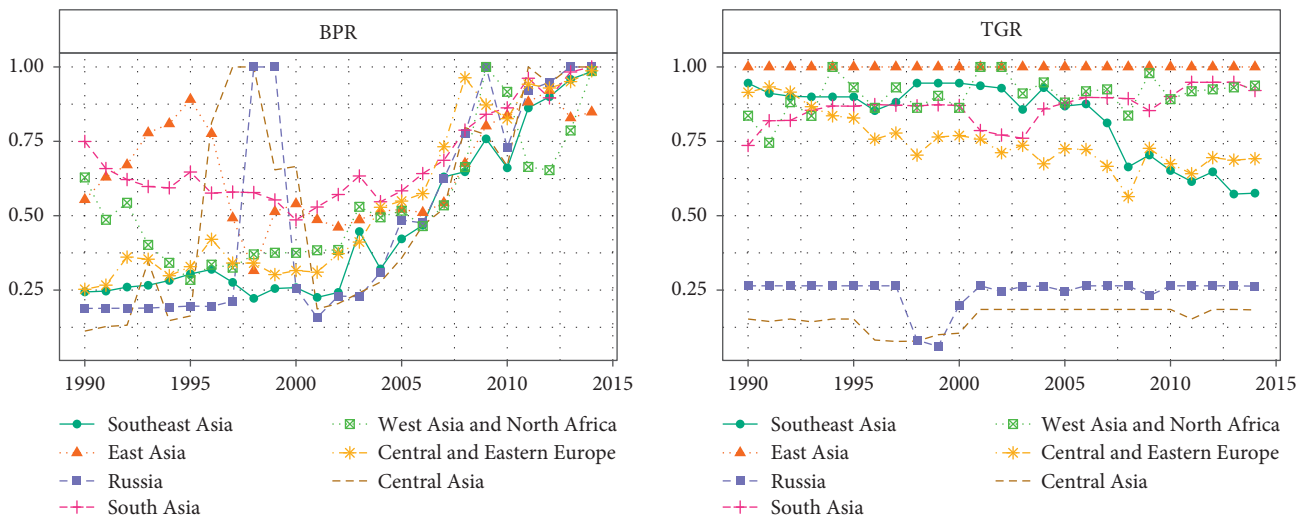FIGURE 3: Annual average carbon emission efficiency by group.

FIGURE 4: Annual average BPR and TGR by the group.

group-frontier carbon emission efficiency and metafrontier carbon emission efficiency of various regions are increasing year by year.

Figure 4 shows the average annual BPR and TGR by group, with BPR on the left and TGR on the right. In the figure on the left, only 3 regions have a BPR of 1 in individual
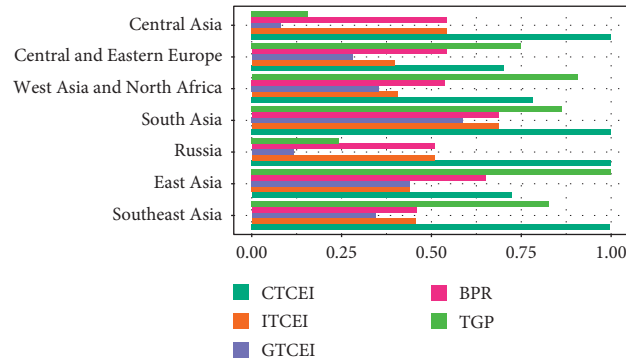
FIGURE 5: Average carbon emission efficiency by group and its decomposition.

years: Russia, West Asia, North Africa, and Central Asia, and BPRs in other regions and years are less than 1. In the figure on the right, the TGR of East Asia is 1, the TGR of Southeast Asia, West Asia, North Africa, South Asia, and Central and Eastern Europe are all close to 1, while the TGR of Russia and Central Asia are both less than 0.25. This shows that, for Russia and Central Asia, the carbon emission efficiency gap between the groups is the main reason hindering the improvement of GTCEI, while for Southeast Asia, Western Asia and North Africa, East Asia, South Asia, and Central and Eastern Europe, the carbon emission efficiency gap within the group is the main factor hindering GTCEI's promotion.

Figure 5 shows the average CTCEI, ITCEI, GTCEI, BPR, and TGP by the group. The CTCEI of each group is close to or equal to 1, indicating that the contemporaneous carbon emission efficiency of each group is at the optimal level. However, both ITCEI and GTCEI are less than 1, indicating that the regional group-frontier carbon emission efficiency and metafrontier carbon emission efficiency are insufficient. From the perspective of ITCEI's ranking: South Asia > Central Asia > Russia > Southeast Asia > East Asia > West Asia and North Africa > Central and Eastern Europe. From the perspective of GTCEI's ranking: South Asia > East Asia > Southeast Asia > West Asia and North Africa > Central and Eastern Europe > Russia > Central Asia. From the comparison of BPR and TGP, except for Russia and Central Asia, BPR > TGP, the rest of the regions are BPR < TGP, indicating that the efficiency loss of GTCEI in Russia and Central Asia mainly comes from the carbon emission efficiency gap between groups, while for other regions it comes from the carbon efficiency gap within the group.

4.2. Panel Unit Root Test. The first step for the investigation of causality is to determine whether the series has any integration orders. For this purpose, this paper first carries out a panel unit root test for each variable. At present, the panel unit root test method is mainly divided into two types. The first type is the same unit root test based on Levin et al. [35] (LLC), Breitung and Das [36] (Breitung), and Hadri and Larsson [37] (Hadri) tests. The other is unit root test based on Im et al. [38] (IPS) and Choi [39] (Fisher). For the sake of

robustness, this paper conducts four panel unit root tests for LLC, Breitung, Fisher, and IPS. The results are reported in Table 4. From the table, it is evident that all variables pass the significance test at least at the 5% significance level, which indicates that all variables are stationary.

4.3. Benchmark Regression Result. In order to clarify the direct impact of freight trade on a host country's carbon emission efficiency, this paper uses the OLS method to estimate the benchmark model. The results are shown in Table 5.

In (1a)–(3a), the coefficients of LIFT are all significantly positive, indicating that freight trade has a promoting effect on carbon emission efficiency of various countries. From the point of view of the coefficient of LIFT, freight trade has the highest promotion effect on the contemporaneous carbon emission efficiency, reaching 0.0684, and the smallest effect on the metafrontier carbon emission efficiency is only 0.0285. However, the promotion effect of each region is not consistent. In (4a), the coefficient of LIFT is positive, but it is not significant at the 10% significance level, indicating that the improvement of freight trade cannot significantly reduce the carbon emission efficiency differences among regions. In (5a), the coefficient of LIFT is significantly negative, indicating that the improvement of freight trade will significantly expand the difference in carbon emission efficiency between different regions, which indirectly is not conducive to the improvement of metafrontier carbon emission efficiency.

From the perspective of control variables, LRED has a significant negative impact on LITCEI, LGTCEI, and LBPR, indicates that the higher the proportion of government expenditure in GDP, the lower the efficiency of intertemporal carbon emissions and the overall efficiency of carbon emissions. It will also increase the carbon emission efficiency gap within the group. LRFE has a significant positive impact on LCTCEI, LITCEI, and LGTCEI, and a significant negative impact on LBPR and LTGR, indicating that the increase in fossil energy dependence will significantly improve the carbon emission efficiency of countries, but it will also solve the carbon emission efficiency gap within and between groups, which indirectly causes a loss of carbon emission efficiency. In (1a)–(5a), the coefficients of

TABLE 4: Panel unit root tests.

Variable	LLC test	Breitung test	IPS test	Fisher test
LCTCEI	−8.8635***	−1.6509**	−9.4577***	−12.0121***
LITCEI	−7.3542***	−2.0389**	−6.8583***	−10.3107***
LGTCEI	−10.2806***	−3.2652***	−6.4187***	−8.8358***
LBPR	−8.1387***	−3.6343***	−8.5008***	−13.0389***
LTGR	−11.2486***	−7.1752***	−10.0967***	−11.6917***
LIFT	−5.6338***	−5.1729***	−2.9788**	−7.8499***
LFDI	−2.5586***	−4.6094***	−3.3514***	−8.2880***
LRED	−7.5905***	−3.3552***	−5.9387***	−12.0561***
LRFE	−6.4840***	−1.4404*	−4.2362***	−7.1025***
LPatent	−4.5581***	−2.7424***	−3.6996***	−10.3693***
LRID	−4.1813***	−1.4641*	−3.0617**	−10.9062***

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

TABLE 5: Benchmark model results.

Variable	LCTCEI (1a)	LITCEI (2a)	LGTCEI (3a)	LBPR (4a)	LTGR (5a)
LIFT	0.0684***	0.0389***	0.0285***	0.0011	−0.008**
	(0.0058)	(0.0051)	(0.0042)	(0.0045)	(0.0034)
LRED	0.155	−0.431***	−0.416***	−0.620***	0.0019
	(0.1751)	(0.1543)	(0.1253)	(0.1353)	(0.1038)
LRFE	2.7469***	1.4071***	1.1454***	−0.670***	−0.656***
	(0.2858)	(0.2517)	(0.2045)	(0.2208)	(0.1693)
LPatent	0.0380**	0.0602***	0.0900***	0.013	0.0239**
	(0.0172)	(0.0151)	(0.0123)	(0.0133)	(0.0102)
LRID	−0.083***	−0.179***	−0.182***	−0.154***	−0.036**
	(0.0270)	(0.0238)	(0.0193)	(0.0209)	(0.0160)
Constant	0.5692***	0.7342***	0.7432***	0.8921***	0.8017***
	(0.1128)	(0.0994)	(0.0807)	(0.0872)	(0.0668)
Section	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	800	800	800	800	800
R^2	0.3972	0.5963	0.6317	0.6337	0.6415

The parenthesis are the robust standard error values: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

LPatent are all positive, indicating that the improvement of the innovation level is not only conducive to the improvement of carbon emission efficiency [40] but also can reduce the carbon emission efficiency gap within and between groups. Contrary to LPatent, the coefficients of LRID are significantly negative, indicating that the level of industrialization will not only inhibit the improvement of carbon emission efficiency but also aggravate the carbon emission efficiency gap within and between groups.

4.4. Heterogeneity Test. Considering that fossil energy consumption is the main source for carbon dioxide, this paper divides the countries along the "Belt and Road" into low fossil energy dependent countries (ALB, ARM, AZE, BGR, CZE, EST, HRV, HUN, ISR, LKA, LTU, LVA, MDA, MKD, SVK, and SVN) according to the median of LRFE, and high fossil energy dependent countries (BLR, CHN, EGY, JPN, KAZ, KOR, MYS, PAK, PHL, POL, ROU, Rus, SAU, SGP, THA, and TUR). The OLS regression results are listed in Table 6.

In (1b)–(3b) and (1c)–(3c), the coefficients of LIFT are significantly positive, indicating that the promotion of

freight trade on a host country's carbon emission efficiency has nothing to do with fossil energy dependence. However, the coefficients of LIFT in (1b) and (2b) are larger than those of (1c) and (2c), and the coefficient of (3b) is smaller than that of (3c). This shows that the improvement of freight trade mainly promotes the current and group-frontier carbon emission efficiency of low fossil energy dependent countries. At the same time, it mainly promotes the metafrontier carbon emission efficiency of high fossil energy dependent countries. In (4b) and (4c), the effect of LIFT on LBRP is positive but insignificant at the 10% significance level. In (5b) and (5c), the influence of LIFT on LTCR was differentiated. In the sample of low fossil energy dependence, the coefficient of LIFT is significantly negative, indicating that the improvement of freight trade will increase the difference in carbon emission efficiency between groups. In the sample of high fossil energy, the coefficient of LIFT is positive but insignificant.

4.5. Mechanism Test. Many studies have shown that the throughput of goods and the scale of import and export trade reflect a country's level of openness. Moreover, trade

TABLE 6: Heterogeneity test results.

Variable	LCTCEI (1b)	LITCEI (2b)	LGTCEI (3b)	LBPR (4b)	LTGR (5b)
Low fossil energy consumption					
LIFT	0.0776***	0.0490***	0.0295***	0.0032	−0.0150***
	(0.0097)	(0.0076)	(0.0066)	(0.0052)	(0.0040)
Constant	0.3905**	0.2686**	0.3319***	0.5597***	0.7790***
	(0.1713)	(0.1341)	(0.1172)	(0.0925)	(0.0713)
Control	Yes	Yes	Yes	Yes	Yes
Section	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	400	400	400	400	400
R^2	0.347	0.6249	0.5752	0.7603	0.4351
High fossil energy consumption	(1c)	(2c)	(3c)	(4c)	(5c)
LIFT	0.0548***	0.0473***	0.0535***	0.0145	0.0019
	(0.0112)	(0.0099)	(0.0073)	(0.0108)	(0.0074)
Constant	0.6156**	2.2646***	1.2025***	2.2722***	−0.1158
	(0.2386)	(0.2100)	(0.1552)	(0.2305)	(0.1571)
Control	Yes	Yes	Yes	Yes	Yes
Section	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	400	400	400	400	400
R^2	0.4646	0.7091	0.7943	0.6305	0.7989

The parenthesis are the robust standard error values: ***$p < 0.01$, **$p < 0.05$, and *$p < 0.1$.

openness helps attract foreign direct investment in a country, thereby enhancing its technical level and environmental quality. This is the "pollution aura" hypothesis [34, 41]. We take FDI as the intermediary variable of this paper and perform regression analysis, and the results are shown in Table 7.

It can be seen from the table that, after adding LFDI, the coefficient of LIFT is consistent with that in Table 5 except for the change in size. This indicates that, although LFDI slightly disturbs the causal relationship between LIFT and the dependent variable, this disturbance is very limited. Judging from the coefficient of LFDI, LFDI only has a significant and negative impact on LITCEI and LGTCEI. This implies that FDI in a host country is not a "pollution halo" effect but a "pollution refuge" effect. In other words, the objective of FDI entering the host country is mainly to circumvent the stricter environmental regulations of the home country, which leads to a decline in the host country's environmental quality. In this research, it is mainly reflected in the reduced group-frontier carbon emission efficiency and global carbon emission efficiency, and the gap between groups widens. Fortunately, the impact of LIFT on LFDI in (6d) is significantly negative, indicating that the increase in freight trade will significantly prevent the entry of FDI and prevent the country from becoming a "pollution refuge."

4.6. Robustness Test. In order to avoid the endogenousness caused by the reverse influence and the omission of the variables, this paper incorporates the first-order lag of the dependent variable into the regression equation, uses the first-order lag and second-order lag of the independent variables as instrumental variables, and then uses the GMM method which estimates the model. The results are shown in Table 8.

In (1e)–(5e), the direction of the LIFT coefficients is consistent with that in Table 7. Hence, our empirical results obtained so far are robust. That is, there is no reverse bias and missing results caused by variables. In addition, the p values of AR (2) and Sargan test are both greater than 10%, indicating no second-order autocorrelation and no weak instrumental variables in the error term.

5. Conclusion and Policy Implications

This paper uses a metafrontier nonradial directional distance function to measure the carbon emission efficiency and efficiency differences of 32 countries along the "Belt and Road" from 1990 to 2014. It then builds an empirical model to examine the impact of freight trade on the carbon emission efficiency. The main conclusions of this paper are as follows.

The CTCEI, ITCEI, and GTCEI gradually decreased to 0.793, 0.436, and 0.325, respectively, indicating room for improvement in the carbon emission efficiency of countries along the "Belt and Road." The carbon emission efficiency measured by traditional nonparametric methods will be significantly overestimated. Over the years, the carbon emission efficiency gap within each region has narrowed, while the gap between regions has widened, resulting in GTCEI losses. Furthermore, only 13 countries have an average CTCEI of 1, indicating that most countries have not achieved the current level of carbon emission efficiency. The main reason is that the carbon emission efficiency gap within group is still large. In terms of groupings, except for East Asia, West Asia, North Africa, and Central and Eastern Europe, the CTCEI of other regions is 1, indicating that these regions are currently at the optimal level of carbon emission efficiency, but they also face a long-term situation of low

Table 7: Mechanism test results.

Variable	LCTCEI (1d)	LITCEI (2d)	LGTCEI (3d)	LBPR (4d)	LTGR (5d)	LFDI (6d)
LIFT	0.0673***	0.0374***	0.0262***	0.0017	−0.0089**	−0.0155***
	(0.0059)	(0.0052)	(0.0042)	(0.0045)	(0.0035)	(0.0044)
LFDI	−0.0664	−0.0993**	−0.1444***	0.0361	−0.0555**	
	(0.0475)	(0.0418)	(0.0337)	(0.0368)	(0.0281)	
Constant	0.5902***	0.7657***	0.7890***	0.8807***	0.8193***	0.3172***
	(0.1138)	(0.1000)	(0.0805)	(0.0880)	(0.0673)	(0.0858)
Control	Yes	Yes	Yes	Yes	Yes	Yes
Section	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes
N	800	800	800	800	800	800
R^2	0.3987	0.5993	0.6404	0.6342	0.6433	0.5156

The parenthesis are the robust standard error values: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

Table 8: Robustness test results.

Variable	LCTCEI (1e)	LITCEI (2e)	LGTCEI (3e)	LBPR (4e)	LTGR (5e)
LIFT	0.0239*	0.0882***	0.0263**	0.0865***	−0.0343**
	(0.0130)	(0.0212)	(0.0109)	(0.0218)	(0.0151)
LCTCEI	0.1367				
	(0.2286)				
LITCEI		0.7007***			
		(0.0868)			
LGTCEI			0.6417***		
			(0.1187)		
LBPR				0.6705***	
				(0.0815)	
LTGR					0.0436
					(0.1819)
AR (2) p value	0.2428	0.8028	0.114	0.5351	0.6821
Sargan p value	0.2716	0.2524	0.1413	0.2581	0.2836
Control	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
N	736	736	736	736	736

The parenthesis are the robust standard error values: *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

ITCEI and GTCEI. Among them, for Russia and Central Asia, the carbon emission efficiency gap between the groups is the main reason hindering the improvement of GTCEI, while for Southeast Asia, Western Asia and North Africa, East Asia, South Asia, and Central and Eastern Europe, the carbon emission efficiency gap within the group is the main factor.

Benchmark regression results show that freight trade is conducive to improving the efficiency of the three types of carbon emissions, but will exacerbate the between-group gap. The heterogeneity test results show that the freight trade mainly promotes the current carbon emission efficiency and group-frontier carbon emission efficiency of low fossil energy dependent countries. It also exacerbates the between-group difference in carbon emission efficiency. Moreover, freight trade mainly promotes the metafrontier carbon emission efficiency of high fossil energy dependent countries. Based on the results of the mechanism test, we can conclude that FDI can lead to the "pollution halo" effect and the "pollution refuge" effect. In other words, the purpose of FDI entering the host country is mainly to circumvent the

stricter environmental regulations of the home country. This can decrease the host country's environmental quality. In this paper, it is mainly reflected in the reduced group-frontier carbon emission efficiency and global carbon emission efficiency. And the between-group gap expands. Fortunately, the impact of LIFT on LFDI is significantly negative, indicating that the increase in freight trade will significantly prevent the entry of FDI and prevent the "pollution refuge" effect. This can thereby indirectly improve carbon emission efficiency and reduce the carbon emission efficiency gap.

With the continuous development of transportation infrastructure and channels, the acceleration of the spatial transfer of production factors such as logistics, human flow, financial flow, and information flow along the "Belt and Road" can rapidly change the spatial transfer of carbon emissions from freight trade among countries. In the presence of climate warming, frequent natural disasters, and tightening of international carbon emission regulations, it is critical to be able to accurately assess the impact of freight trade on the carbon emission efficiency of countries along

the "Belt and Road" and to achieve a win-win outcome for economic development and environmental quality improvement. Therefore, in order to effectively improve the carbon emission efficiency and reduce the differences in the scale and intensity of carbon emission space transfer in freight trade among countries, this paper proposes the following three policy suggestions. Firstly, a country's government can set an appropriate upper limit on the emission from freight trade in accordance with its economic and social development goals. Secondly, a country can improve its national energy consumption structure and introduce relevant policies to improve its transportation infrastructure and technological innovation. For example, it can aim to eliminate high-carbon transportation vehicles as soon as possible and promote energy efficient and clean freight vehicles. Thirdly, countries along the "Belt and Road" can strengthen cooperation, establish an early warning system for carbon emissions transfer due to freight trade, and provide matching incentives and penalties related to carbon emissions from freight trade to guide the low-carbon and sustainable development of freight trade in these countries.

Data Availability

Our original data were obtained from World Bank Development Indicators (WDI), which can be accessed in the CSMAR database (http://www.gtadata.com).

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Contributions

J.H., Q.H., and H.S. conceived and designed the research question. J.H. constructed the models and analyzed the optimal solutions. J.H., Y. Luo, and Y. Li wrote the paper. Q.H. and H.S. reviewed and edited the paper. All authors read and approved the manuscript.

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