Tracking Transfer of Carbon Dioxide Emissions to Countries along the Silk Roads Through Global Value Chains

ZHANG Guangyuan¹, ZHENG Zhi²,³, WUZHATI Yeerken²,³
(1. School of Electronic Engineering and Computer Science, Queen Mary University of London, London, UK; 2. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; 3. Key Laboratory of Regional Sustainable Development Modeling, Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China; 4. College of Resources and Environment, University of Chinese Academy of Sciences, Beijing 100049, China)

Abstract: The Belt and Road Initiative (BRI) has aroused rich discussions about the possible increase in carbon dioxide emission under the arduous global carbon dioxide emission reduction task. Adopting the methods of input-output technique and complex network analysis, we first construct a fairer method to trace carbon dioxide emission transfer based on global value chains, then trace the source of carbon dioxide emission transfer to the Silk Roads countries with a long-term multiple regional input-output database. We find that, first, after the proposal of the BRI, the total direct carbon dioxide emissions of the Silk Roads countries and China’s proportion of carbon dioxide emission transfer to the other Silk Roads countries have both declined. Second, the Silk Roads countries are generally the net receivers of carbon dioxide emission transfer, and the inflow is mainly distributed in Southeast Asian countries and core countries in other sub-regions. Then, the transfer of carbon dioxide emission accepted by the Silk Roads countries comes mostly from large developing countries, such as China, Russia, and India, and developed countries, such as the United States, Japan, and Germany. The products are mainly concentrated in energy and chemical industries, as well as heavy industries, such as mining and quarrying, and metal products. We suggest that, due to the high degree of spatial and industrial concentrations of carbon dioxide emission transfer, it is necessary to make targeted policies for these countries and industries to reduce these transfers.

Keywords: The Belt and Road Initiative (BRI); carbon dioxide emission; global value chain; carbon dioxide transfer; emission responsibility; emission reduction

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1 Introduction

Rapid industrialization has promoted global economic growth and improved living standards worldwide. However, human activities are also increasingly negatively impacting the environment. The massive usage of fossil energy has dramatically increased greenhouse gas emissions (Zheng, 2021). The fifth report of the United Nations Intergovernmental Panel on Climate Change (IPCC) states that human activities are clearly impacting the climate system (Mastrandrea et al., 2010). Many changes observed since the 1950s have been unprecedented. In this context, reducing carbon dioxide emissions has become an essential task. Since the 1990s, globalization has been advancing rapidly, the economic organization has been reformed, and the global carbon
dioxide emission pattern has also undergone tremendous changes (Yan et al., 2020; Zhao and Liu, 2020; Fan et al., 2021). With the deepening of labor division, different production stages are able to break through the geographical restrictions and find the best locations on a global scale. United Nations Conference on Trade and Development (UNCTAD, 2013) estimates that 80% of the world trade takes place in global value chains. In this context, the production and outsourcing activities of any country will affect and be affected by the production activities of other countries, and the carbon dioxide emission caused by these production activities will also be significantly affected by other countries (Zhong et al., 2018). This makes a country or region’s responsibility for carbon dioxide emission exceed its own national borders, and the corresponding carbon dioxide emission reduction tasks have become transnational in nature. It is vital to coordinate transnational production relationships to reduce carbon dioxide emissions. Therefore, clarifying the transfer process of carbon dioxide emission in the context of global value chains is of great significance to achieving the aim of global carbon dioxide emission reduction (Meng et al., 2018).

In 2013, China proposed the BRI with the aim of building a win-win platform for international economic cooperation (Liu et al., 2018; Dunford and Liu, 2019). So far, 148 countries and 32 international organizations have signed cooperation documents for the joint construction of the BRI, including 64 core countries. The BRI has quickly attracted huge attention from people from all walks of life in the world because of its huge volume and grand vision. In addition to its impact on the global economy, its environmental impact on the Silk Roads countries, especially carbon dioxide emission, has received extensive attention (Ascensão et al., 2018; Hafeez et al., 2019; Teo et al., 2019; Butt and Ali, 2020; Ng et al., 2020). While the BRI brings new development opportunities to the Silk Roads countries (Zheng et al., 2021a; b; c), new projects and industrial development may lead to an increase in carbon dioxide emissions. Therefore, many scholars worry that the large-scale infrastructure construction and the usage of energy resources brought about by the BRI will increase the total amount of carbon dioxide emission in the Silk Roads countries (Ascensão et al., 2018; Saud et al., 2019; Rauf et al., 2020). The Silk Roads countries are mainly developing countries with high carbon dioxide emissions compared with other countries. The carbon dioxide emission research on the BRI is not only conducive to promoting economic development with low carbon dioxide emission in the Silk Roads countries but also has great significance for global carbon dioxide emission reduction.

Existing research on carbon dioxide emission in countries along the Silk Road is mainly focused on the exploration of the influencing factors (Liu and Hao, 2018; Fan et al., 2019; Sun et al., 2019; Zhu and Gao, 2019; Deng and Du, 2020; Hu et al., 2020), as well as the description of the pattern and its evolution of carbon dioxide emission in different industries (Zhang et al., 2019; Tao et al., 2020). However, the sources of carbon dioxide emission transfer to the Silk Roads countries through global value chains are rarely involved. The Silk Roads countries are mostly developing countries with relatively low-end labor divisions in global value chains and receive a large amount of carbon dioxide emission transfer from other countries passively. Tracing the source of these carbon dioxide emission transfers has important reference significance for reducing carbon dioxide emission in the Silk Roads countries. In term of the measurement of carbon dioxide emission transfer through global value chains, one of the most central issues is identifying its source and destination. At present, most of the carbon dioxide emission transfer research is about the embodied carbon (Liu et al., 2015a; b; Han et al., 2018; Zhong et al., 2018; Lu et al., 2020; Wu et al., 2020; Yan et al., 2020; Zhao and Liu, 2020), which is typically consumer responsibility principle, because the inherent logic of this method is that the countries consuming these products should be responsible to these carbon dioxide emissions. However, there have been rich discussions and attempts in academia on the principle of carbon dioxide emission responsibility distribution. Among them, the irrationality of the producer responsibility principle and the consumer responsibility principle has been widely accepted due to their obvious one-sidedness (Kondo et al., 1998; Fery, 2003; Lenzen et al., 2007). Therefore, it is not reasonable to trace the transfer source of carbon dioxide emission in the Silk Roads countries by means of embodied carbon (for example, Han et al., 2018). Besides, the more reasonable principle of common responsibility principle has not formed a universally acceptable scheme in terms of proportions. Therefore, the method to
trace transnational carbon dioxide emission transfer still needs further improvement.

Global value chains are usually organized by the firms that own the final products, which often lead firms in different industries are established in high-income or a few upper-middle-income countries. Through the organization of global value chains, they tend to outsource the production stages with high carbon dioxide emission and low value-added, leaving only the production stages with high value-added and low carbon dioxide emission, such as research and development (R&D), sales, and after-sales stages. Therefore, in the context of global value chains, the transnational transfer of global carbon dioxide emission mainly comes from the process in which the owner of the final product transfers its emissions to the firms in other countries. To complete the production of a product, the owner of the product needs to emit all carbon dioxide emissions in the production process when there is no international division of labor. Therefore, from this logic, these carbon dioxide emissions are caused by the country where the product ultimately belongs. Therefore, when tracing the origin of carbon dioxide emission in these production processes, it is reasonable to attribute the source to the countries where the final product belongs. Based on this logic and the above background, the aim of this study is to trace the source of carbon dioxide emission transfer to the Silk Roads countries through the global value chains with long-term input-output data.

The potential contributions of this research are in two aspects. First, in terms of research methods, we innovate the measurement method of tracing transnational carbon dioxide emission transfer under the global value chains. Based on the shortcomings of existing measurement methods, this study proposes a carbon dioxide emission transfer source tracing method based on the country where the final product belongs. This measurement method is not only applicable to this study but also to any research that relates to the measurement of carbon emissions transfer, which will contribute to carbon emissions research by offering a fairer and applicable method for measuring the transfer of carbon emissions. Second, in practice, we have carried out an in-depth calculation of the transfer sources of carbon dioxide emission undertaken by the Silk Roads countries from both space and product levels. This is conducive to the international community’s fairer understanding of the responsible sources of high carbon dioxide emissions in the silk road countries, and can serve as an effective reference for making relevant policies and measures to reduce carbon dioxide emission of the Silk Roads countries.

2 Methodology and Data

2.1 Methodology

This study mainly uses the input-output technique in method. By using the input-output technique, a carbon dioxide emission transfer source tracing method based on the country where the final product belongs is constructed. In addition, in order to better show the structure and characteristics of the global carbon dioxide emission transfer networks, this study also employs a complex network analysis method. Finally, in terms of visualization, we use Gephi 0.9.2 network analysis software to visualize the data and use different colors to distinguish different network communities.

(1) Input-output method and the carbon dioxide emission transfer source tracing method based on the country where the final product belongs

Using an input-output table, we can analyze the cross-border flows of intermediate goods and their value-added. Suppose that there are \( m \) economies and \( n \) industries. The multiple regional input and output (MRIO) structure can be expressed as follows:

\[
\begin{pmatrix}
X^1 \\
X^2 \\
\vdots \\
X^m 
\end{pmatrix} = 
\begin{pmatrix}
A^{11} & A^{12} & \cdots & A^{1m} \\
A^{21} & A^{22} & \cdots & A^{2m} \\
\vdots & \vdots & \ddots & \vdots \\
A^{m1} & A^{m2} & \cdots & A^{mm} 
\end{pmatrix}
\begin{pmatrix}
X^1 \\
X^2 \\
\vdots \\
X^m 
\end{pmatrix} + 
\begin{pmatrix}
Y^1 \\
Y^2 \\
\vdots \\
Y^m 
\end{pmatrix}
\]

\[
\begin{pmatrix}
B^{11} & B^{12} & \cdots & B^{1m} \\
B^{21} & B^{22} & \cdots & B^{2m} \\
\vdots & \vdots & \ddots & \vdots \\
B^{m1} & B^{m2} & \cdots & B^{mm} 
\end{pmatrix}
\begin{pmatrix}
Y^1 \\
Y^2 \\
\vdots \\
Y^m 
\end{pmatrix}
\]

where \( i \) represents \( i \)th country, \( j \) represents the \( j \)th economy, \( m \) represents the number of input-output economy. \( X^i \) represents the total \( n \times 1 \) output vector of the economy, and \( A^{ij} \) represents the \( n \times n \) input-output direct consumption coefficient matrix. The matrix is formed by the proportion of the part in economy \( i \) in the intermediate input of economy \( j \) to the total input of economy \( j \). \( Y^i \) represents the total amount of \( n \times 1 \) final product demanded by each economy for economy \( i \). \( B^{ij} \) represents the Leontief inverse matrix of the input-out-
put matrix.

Based on the Koopman, Powers, Wang, and Wei method proposed by Koopman et al. (2008; 2010; 2012a; 2012b), $V$ represents the proportion of the value-added (value-added/total output) and the sum of the direct and indirect output value-added for one unit of one country is denoted as $V + VA + VAA + \cdots = V(I - A)^{-1} = VB$ (Cheng, 2015). $VB$ is the total value-added multiplier matrix. In this calculation, $V$ is the diagonal matrix formed by the diagonal value distribution of the direct value-added coefficients of industries in various countries, $B$ is the Leontief inverse matrix of different sectors in multiple countries, and $Y$ is the angular matrix pair of the final products of each sector in various states and the diagonal distribution. The value added by the final products of a country can be calculated as follows:

$$ VBY = \begin{bmatrix} V_1B_11Y_1 & V_1B_12Y_2 & \cdots & V_1B_{1m}Y_m \\ V_2B_21Y_1 & V_2B_22Y_2 & \cdots & V_2B_{2m}Y_m \\ \vdots & \vdots & \ddots & \vdots \\ V_mB_m1Y_1 & V_mB_m2Y_2 & \cdots & V_mB_{mn}Y_m \end{bmatrix} $$

(2)

$\bar{C}$ represents the diagonal matrix formed by the direct carbon dioxide emission intensity of each country and industry along the diagonal, where

$$ \bar{C}X = \bar{C}(I - A)^{-1}Y = \bar{C}BY $$

(3)

The carbon dioxide emission in the production process can be completely decomposed into:

$$ \bar{C}BY = \begin{bmatrix} \bar{C}_1B_11Y_1 & \bar{C}_1B_12Y_2 & \cdots & \bar{C}_1B_{1m}Y_m \\ \bar{C}_2B_21Y_1 & \bar{C}_2B_22Y_2 & \cdots & \bar{C}_2B_{2m}Y_m \\ \vdots & \vdots & \ddots & \vdots \\ \bar{C}_mB_m1Y_1 & \bar{C}_mB_m2Y_2 & \cdots & \bar{C}_mB_{mn}Y_m \end{bmatrix} $$

(4)

Among them, $\bar{C}_mB_{mn}Y_n$ represents the carbon dioxide emission transferred to country $m$ from country $n$, where the final product is produced. In the high probability case, the country where the final product is produced is the country where the product belongs, which means that $\bar{C}_mB_{mn}Y_n$ represents the carbon dioxide emission transferred from country $n$ to country $m$ through global value chains. However, the outsourcing of final product assembly activities is not uncommon today. For example, a large number of Apple mobile phones are assembled in China. China is the producer of these final Apple mobile phones, but the United States owns these phones. In order to correct this deviation, we identify the country where the final product belongs according to the proportion of the value-added obtained by each country in a certain final product.

Normally, the lead firm that outsources assembly activities can obtain the highest proportion of value-added. Therefore, we identify the country of product $Y_n$ according to Formula (5):

$$ \text{Maximum}(V_mB_{mn}Y_n) = V_{\tilde{n}}B_{\tilde{n}n}Y_n $$

(5)

Among them, $\tilde{n}$ is the country where the final product $Y_n$ belongs. Therefore, it can be concluded that $\bar{C}_mB_{mn}Y_{\tilde{n}}$ represents the transfer of carbon dioxide emission from country $n$ to country $m$ through global value chains.

2.2 Complex network analysis

To analyze the structure of carbon dioxide emission transfer networks, a cohesive subcommunities analysis was used to identify the communities and their evolution in the networks. The cohesive subcommunities analysis uses topological relations and attributes to ascertain the community structure in the network. The main characteristic of the community structure is that the nodes in a community are closely related, whereas the associations of the nodes between communities are relatively weak. There are many types of network community detection methods (Girvan and Newman, 2002; Clauset et al., 2004; Newman and Girvan, 2004; Radicchi et al., 2004; Wu and Huberman, 2004; Pons and Latapy, 2006; Newman, 2006), and the fast unfolding method was selected for this study to modularize the network (Blondel et al., 2008) (the resolution is uniformly set to 1). To avoid the interference of complex data and facilitate visualization, a backbone network was selected as a replacement for the entire network (Boguñá, 2007). Moreover, to avoid the incorrect judgment of a network as the top network when the results reflect some internal ‘island’ countries merely trade with each other, this study selects the top five networks.

2.2.1 Research area and data sources

Liu et al. (2020) identified 64 countries that are widely used in many academic studies and official news reports dealing with the BRI as the Silk Roads countries other than China. In this study, due to the lack of Palestine and East Timor in the database available, the Silk Roads countries refer to a total of 62 countries, which are listed in Table 1.
To trace the global value chain connections between countries, a multi-region input-output (MRIO) table is needed. After comparing the widely used MRIO tables, such as the Global Trade Analysis Database (GTAP), the Organization for Economic Co-operation and Development (OECD) Database, the World Input-Output Database, and the University of Sydney Input-Output Table (Eora MRIO), we choose the Eora MRIO database because of its wide coverage of both the geographic scope of 188 economies and the sectoral scope of 24 industries. The Eora database covers all Silk Roads countries except for Palestine and East Timor and covers a long-time span from 1995 to 2015 and includes a carbon dioxide emission satellite account (https://www.worldmrio.com/). In addition, this study uses the carbon dioxide emission data published by the World Bank to correct the total carbon dioxide emission data in the Eora database (https://data.worldbank.org/) (Zheng et al., 2021).

### Table 1  Research area (the Silk Roads countries)

| Region                        | Country                                                                 |
|-------------------------------|--------------------------------------------------------------------------|
| Central Asia                  | Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan              |
| Mongolia and Russia           | Mongolia, Russia                                                          |
| Southeast Asia                | Vietnam, Laos, Cambodia, Thailand, Malaysia, Singapore, Indonesia, Brunei, Philippines, Myanmar |
| South Asia                    | India, Pakistan, Bangladesh, Afghanistan, Nepal, Bhutan, Sri Lanka, Maldives |
| Central and Eastern Europe    | Poland, Czech Republic, Slovakia, Hungary, Slovenia, Croatia, Romania, Bulgaria, Serbia, Montenegro, Kingdom of Macedonia, Bosnia and Herzegovina, Albania, Estonia, Lithuania, Latvia, Ukraine, Belarus, Moldova |
| West Asia and the Middle East | Turkey, Iran, Syria, Iraq, the United Arab Emirates, Saudi Arabia, Qatar, Bahrain, Kuwait, Lebanon, Oman, Yemen, Jordan, Israel, Armenia, Georgia, Azerbaijan, Egypt |

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### 3 Results and Analysis

#### 3.1 Evolution of direct carbon dioxide emission in the Silk Roads countries

First, the Silk Roads countries are the countries with high carbon dioxide emission and high carbon dioxide emission growth rates compared with other countries. Among them, China is the country with the largest proportion and the fastest growth rate. The total amount of direct carbon dioxide emission in the Silk Roads countries has basically maintained continuous growth from 1995 to 2015 (Fig. 1), increasing from 9785 kt in 1995 to 21 920 kt in 2015, with an average annual growth rate of 4.12 %, higher than the world’s average of 2.24%. In 1995, it accounted for 42.34% of the global carbon dioxide emission. By 2015, this proportion had increased to as high as 60.93%. It can be seen from Fig. 1 that China’s direct carbon dioxide emission accounts for a large proportion of the Silk Roads countries. Excluding China, in 2015, the total direct carbon dioxide emission of other Silk Roads countries accounted for a significant drop in the global share of 29.53%. In 2015, China alone accounted for 51.54% of carbon dioxide emissions in the Silk Roads countries. The average annual growth rate of direct carbon dioxide emission in the Silk Roads countries without China drops sharply to 2.60%, but it is still higher than the global average.

In terms of the evolution, before 2001, the growth rate of total direct carbon dioxide emission in the Silk Roads countries fluctuated around 1%, but the growth rate rose sharply in 2001, and by 2003, the growth rate reached 10%. In 2001, China joined the WTO. With cheap resources and labor, China quickly undertook a large number of global production transfers and gradually became a new world factory. Correspondingly, its growth rate of carbon dioxide emission grows sharply between 2001 to 2003. After 2003, except for the short fluctuations caused by the 2008 financial crisis, it has continued to show a downward trend. By 2015, the average annual growth rate dropped to 1.11%. In contrast, the growth rate of carbon dioxide emission in the Silk Roads countries without China has been more gradual and has been keeping a small gap with the global average. The Asian financial crisis in 1997 caused a significant decline in the growth rate of carbon dioxide emission in the Silk Roads countries without China, with a negative growth rate of −1.47%, but then resumed growth. From 2001 to 2005, its growth rate was slower than the global average. Between 2006 and 2011, its growth rate was slightly higher than the global growth rate. When the BRI was proposed in 2013, the growth rate of carbon dioxide emission was slightly lower than
the global growth rate. The former was 1.13%, and the latter was 1.25%. In the following two years, the growth rates of carbon dioxide emission in the Silk Roads countries and the Silk Roads countries without China have both declined. This means that the proposal of the BRI in 2013 did not significantly accelerate the growth of carbon dioxide emission in the Silk Roads countries.

3.2 The Silk Roads countries in global carbon dioxide emission transfer networks
First, from the perspective of outflow networks, the core countries in global carbon dioxide emission transfer networks are mainly the United States, Japan, and Germany (Fig. 2). From 1995 to 2015, the concentration of the outflow network was high, and the top five countries accounted for about 50% of the total outflow network. In 1995, the top five countries were the United States, Japan, Germany, France, and Italy. Among them, the United States is the highest, accounting for 16.72%. As the only superpower, the United States, with its strong economic size and technological advantages, is able to organize its production network on a global scale and transfer the low-end production stages with high carbon dioxide emission to other countries while only retaining high-end production stages with carbon dioxide emission to other countries. Japan and Germany accounted for 12.43% and 11.01%, respectively. In the 1950s, the United States gradually transferred traditional industries such as steel and textiles to Japan and the former Federal Republic of

Fig. 1 Total amount and growth rate of direct carbon dioxide emission. The data of China do not include Hong Kong, Macao and Taiwan of China

Fig. 2 Outflow networks of global carbon dioxide emission transfer. The upper arcs represent outflows, the size of circles represent the amount of outflows
Germany when adjusting its domestic industrial structure, which led to a substantial increase in industrial production in Japan and Germany and helped them establish their strong industrial capacities. In the 1970s and 1980s, Japan and Germany transferred low-end production stages to other countries, mainly retaining high-value-added production stages. In this way, they transferred a large amount of carbon dioxide emission through global value chains by transferring the production stages of high carbon dioxide emission to other countries.

By 2001, the top three countries had not changed, but Germany surpassed Japan and became the second-largest country in the outflow network. They accounted for 9.79% and 9.50%, respectively, and decreased significantly compared to the year 1995. The proportion of the United States rose sharply to 23.29%. The Asian financial crisis in 1997 caused severe damage to the Japanese economy, and Germany was also affected. As a result, their industrial production activities were reduced. Comparatively, the United States’ status as the core of the global economy was constantly improving. By the BRI was proposed in 2013, China rose from the eighth in 2001 to the second, while Germany and Japan dropped to the third and the fourth respectively. With the growth of economic strength, China began to transfer some low-end production stages to Southeast Asia and other countries. As a result, the transfer of carbon dioxide emission through global value chains has increased substantially, accounting for an increase from 2.14% in 1995 to 12.90% in 2015. Two years after the BRI was proposed, the proportion of carbon dioxide emission outflow from China rose slightly to 13.42%, while that in the United States rose to 18.45%. It can be seen that since 1995, the United States has been occupying a core position in the global carbon dioxide emission outflow networks, while China is the country with the fastest growth rate of carbon dioxide emission transfer.

Compared with the outflow network, the inflow network mainly centers in China, the United States, and Russia (Fig. 3). The total proportion of the inflows of carbon dioxide emission transfer of the top five countries in the network is about 55%. In 1995, carbon dioxide emission transfer accepted by China accounted for the highest share of 18.02% in the world, followed by the United States and Russia, accounting for 17.39% and 11.69%, respectively. As the largest developing country, China has accepted a large number of high carbon dioxide emission production stages, while the United States provides a large number of high-end components for the production of products in other countries. Therefore, they all accept a large amount of carbon dioxide emission transfer. Similarly, although the Soviet Union disintegrated in 1992, Russia is still at the core of the economy in the former Soviet Union countries, so it also exports a large number of intermediate products for production in the former Soviet Union countries. At the same time, Russia is also an important oil-exporting country. While providing oil to the world, it also produces a large amount of carbon dioxide emission during the oil production process.

Fig. 3 Inflow networks of global carbon dioxide emission transfer. The lower arcs represent inflows, the size of circles represent the amount of inflows.
By 2001, due to the bursting of the Internet bubble in 2000, the growth rate of global carbon dioxide emission dropped sharply (Fig. 1), and China and the United States were affected mostly. At this time, although China still ranked first, its proportion dropped to 14.92%. At the same time, the ranking of the United States dropped to third place, at 11.43%. In comparison, Russia, which has a relatively closed economic development, received less impact, and its proportion rose to 13.67% and ranked second. By 2013, the top three rankings did not change, but the transfer was more concentrated on China. China’s proportion rose to 25.35%, while Russia and the United States accounted for 11.69% and 10.39%, respectively. By 2015, China’s share rose to 26.03%, while Russia and the United States declined slightly to 11.31% and 9.24%, respectively. It is clear that the inflow network is more concentrated than that of the outflow network, and China has always been the country that receives the largest carbon dioxide emission transfer.

In terms of the position of the Silk Roads countries in the network, first, the Silk Roads countries are divided into two communities. Central Asia and Central and Eastern European countries mainly belong to the community with Germany and Russia as the core, while the other countries belong to the community with Japan and China as the core. Second, from the perspective of inflow and outflow, the Silk Roads countries are generally net receivers of carbon dioxide emission transfer in the network, and the volume is constantly expanding. In 2015, the inflow of carbon dioxide emission transfer was mainly distributed in Southeast Asian countries and core countries in other sub-regions, such as India in South Asia, Saudi Arabia in West Asia, Kazakhstan in Central Asia, Ukraine, and Belarus in Central and Eastern Europe. Among them, India receives the largest amount of transfer, accounting for 19.98% of the total inflows of the Silk Roads countries, and Saudi Arabia occupies second place with 8.54%. Ukraine and Kazakhstan ranked third and fourth, accounting for 6.80% and 6.69%, respectively. In addition, the other countries with a proportion of more than 5% include Belarus and Indonesia.

### 3.3 Sources of carbon dioxide emission transfer to the Silk Roads countries without China

From a spatial perspective, carbon dioxide emission transfer sources of the Silk Roads countries without China mainly come from large developing countries, such as China, Russia, and India, and developed countries, such as the United States, Japan, and Germany (Fig. 4). In 2015, the top ten countries that accounted for the transfer of carbon dioxide emission transfer to the Silk Roads countries were China, the United States, Japan, Germany, Russia, Italy, South Korea, France, India, and the United Kingdom. The top ten countries accounted for 56.48% of the total global transfer. Among them, China ranked first, accounting for 11.45%, and the United States and the United Kingdom occupied second and third positions, with 9.60% and 7.23%, respectively.

From the perspective of evolution, in 1995, Germany ranked first with a proportion of 10.06%, the United States ranked fourth with a proportion of 8.16%, while China ranked ninth with a proportion of only 2.81%. From 1995 to 2000, the proportion of the United States increased rapidly and surpassed Germany, Japan, and Russia to become the country that transferred the largest amount of carbon dioxide emissions to the Silk Roads countries in 1997. After 1997, the proportion of the United States has been showing a downward trend, but before 2008, the United States always occupied the first position. China is the country with the fastest increase in its proportion. From 1995 to 2011, China’s proportion was in a stage of rapid increase, especially after joining the WTO in 2001. In 2007, China already surpassed Ja-
Pan and Germany to the second position. In 2009, China began to become the country that transferred the largest amount of carbon dioxide emissions to the Silk Roads countries. Among the top ten countries, the country that shows a continuous increase is another high-developing country India. From 1995 to 2014, the proportion of India has always been increasing, but its growth rate is lower than that of China, and its ranking grew from 24th in 1995 to 10th in 2015. Compared with the continuous rise of China and India, the proportions of the other top ten countries except for the United States have shown a downward trend.

After the proposal of BRI, China’s transfer of carbon dioxide emission to the Silk Roads countries showed a downward trend, from 12.18% in 2013 to 11.45% in 2015. Comparatively, the proportions of countries such as the United States, Japan, and Germany have all increased. Due to the significant changes in carbon dioxide emission over the years, historical carbon dioxide emission is worthy of attention (Matthews, 2016). From 1995 to 2015, the United States ranked first in the total amount of carbon dioxide emission transferred to the Silk Roads countries, accounting for 10.28% of the total, followed by China and Japan, accounting for 7.69% and 7.68%, respectively. The statistics show that the implementation of the BRI did not make China transfer more carbon dioxide emissions to the Silk Roads countries. On the contrary, because of China’s low carbon dioxide emission technology, and the popularization of carbon dioxide emission control standards, the transfer of the carbon dioxide emission from China to the Silk Roads countries has declined. Furthermore, from a historical perspective, the United States has transferred the most carbon dioxide emissions to the Silk Roads countries. In addition, the total amount of carbon dioxide emissions transferred from Japan and Germany is equivalent to that of China. Therefore, the responsibility for the high carbon dioxide emission of countries along the Silk Road is not caused by one certain country but by multiple sources.

Then, on the industry level, the top five industries that transfer the largest proportion of carbon dioxide emission transfer to the Silk Roads countries were Electricity, gas and water; Petroleum, chemical and non-metallic mineral products; Transport; Mining and quarrying; and Metal products in 2015. Compared with space, the transfer of carbon dioxide emission to the Silk Roads countries shows a higher degree of concentration at the industrial level (Fig. 5). In 2015, the top five industries accounted for 90.85% of the total. Among them, Electricity, gas and water occupy the first place, with a proportion of 33.96%. The Silk Roads countries are mostly developing countries with relatively old energy structures and use a large amount of fossil energy. As a result, these product sectors emit a huge amount of carbon dioxide emissions. Petroleum, chemical and non-metallic mineral products ranked second and accounted for 22.06%. The Transport industry currently mainly relies on oil extracted from petroleum as a source of power, such as gasoline, diesel, and aviation kerosene, which generates a large amount of carbon dioxide emission during operation, accounting for 17.74%. Mining and quarrying and Metal products are heavy industries that emit a large amount of carbon dioxide during production activities, such as consuming fuel when running mining machines and burning coal in steelmaking, accounting for 12.81% and 4.28%, respectively.

From the perspective of changes in the proportion, the increase is mainly concentrated in the two industrial sectors of Petroleum, chemical and non-metallic mineral products, and Transport, with the proportions increasing by 2.16% and 2.12%, respectively. The proportion of Electricity, gas and water increased slightly, only by 1%. The decline in the proportion is mainly in the Mining and quarrying and Metal products industry sectors. It is worth noting that the transfer of carbon dioxide emission in the service industry is generally small. For example, the proportions of carbon dioxide emission in Private households and Maintenance and repair sectors are both less than 0.1%, and they are still in a downward trend. This high concentration on industries is more conducive to the targeted policies making to control carbon dioxide emission.

In order to make the analysis results more practical and guidable, we further explore which countries’ industries have transferred the most carbon dioxide emission to the Silk Roads countries through global value chains. Countries with a single industry occupying more than 1% of the total global carbon dioxide emission transfer to the Silk Roads countries in 1995 include Japan, Russia, Germany, and the United States. Among them, Germany mainly includes three industrial sectors, namely, Metal products, Electrical and machinery, Electricity, gas and water, which account for 1.09%, 1.55%,
and 1.61% of the overall network, respectively. Japan includes three sectors, namely Metal products, Electricity, gas and water, and Public administration, accounting for 1.70%, 2.16%, and 1.15%, respectively. Russia includes four sectors. In addition to the two heavy industry sectors, Metal products and Electricity, gas and water, it also includes two service sectors, including Post and telecommunications, and Public administration. The four industries account for 1.18%, 2.03%, 1.15%, and 1.35%, respectively. Finally, the United States mainly includes three industrial sectors, in addition to the heavy industry Electrical and machinery, it also includes two service sectors, including Financial intermediation and business activities, and Public administration, accounting for 1.12%, 2.19%, and 1.09% respectively.

The Silk Roads countries should make targeted policies to reduce the carbon dioxide emission transfer in these countries’ industries through global value chains.

4 Discussion

First, after the proposal of BRI, international concerns about carbon dioxide emission in the Silk Roads countries are reasonable (Ascensão et al., 2018; Saud et al., 2019; Rauf et al., 2020). The quantitative results of this study show that although the United States has the largest outflows of carbon dioxide emission transfers in the world, since 2010, China has accounted for the largest share of carbon dioxide emission transfers to the other Silk Roads countries through global value chains. In the construction projects carried out in the Silk Roads countries, China should actively implement carbon dioxide emission control measures to prevent the total amount of carbon dioxide emission in the Silk Roads countries from further increasing.
However, the claim that China has transferred more carbon dioxide emissions to the Silk Roads countries after the BRI was proposed is not accurate, and it is biased to deny the BRI from a negative perspective. First, as shown in Fig. 4, after the BRI was proposed in 2013, China’s share of carbon dioxide emission transfer to the Silk Roads countries has continued to decline, while countries such as the United States and Japan are rising. Second, in addition to China, the United States, Japan, Germany, and Russia have also transferred a large amount of carbon dioxide emission. Among them, the proportions of the United States and China are close. Japan, Germany, and Russia all account for more than 5% of the global transfer. Therefore, these countries all bear important responsibilities for carbon dioxide emission in the Silk Roads countries. Third, from a development perspective, the process of economic development in middle or low-income countries will inevitably be accompanied by industrialization, and the latter will bring about an increase in carbon dioxide emission. Therefore, low-income countries are faced with a trade-off between economic development and increased carbon dioxide emission (Murthy et al., 1997; Heil and Selden, 2001; Hailemariam et al., 2020). However, poor low carbon dioxide emission is not the goal pursued by human development. Therefore, an increase in carbon dioxide emissions is inevitable. Fourth, from the perspective of low carbon dioxide emission technology transfer, construction projects carried out in the Silk Roads countries by countries such as China will not necessarily increase carbon dioxide emission in the host countries. On the one hand, the development of new projects will bring about a certain amount of carbon dioxide emission, but on the other hand, higher standards of construction requirements and the transfer of low carbon dioxide emission technology can reduce the carbon dioxide emission compared to the host country’s independent construction.

5 Conclusions

Adopting input-output technique and complex network analysis, by using a long-term input-output database, we first constructed the carbon dioxide emission transfer source tracing method based on the country where the final product belongs and traced the source of carbon dioxide emission transfer through global value chains to the countries along the Silk Road in multi-level with this method. The main findings are as follows.

First, the Silk Roads countries are countries with high carbon dioxide emission and high carbon dioxide emission growth rates. The total amount of direct carbon dioxide emission in the Silk Roads countries has basically maintained a continuous growth from 1995 to 2015, and the annual average growth rate is higher than that of the world. The reason for its high proportion and high growth rate mainly comes from China. In 2015, China accounted for more than 50% of carbon dioxide emissions in the Silk Roads countries. Except for China, the growth rate of carbon dioxide emission in other Silk Roads countries was comparable to that of the global average growth rate.

In the global carbon dioxide emission transfer network, the United States, Japan, and Germany occupy the core positions of the outflow network. These countries transfer the most carbon dioxide emission to other countries through global value chains. China, the United States, and Russia occupy the core positions in the carbon dioxide emission inflow network. The Silk Roads countries are divided into two communities in the network. Central Asia and Central and Eastern European countries mainly belong to the community with Germany and Russia as the core, while the other Silk Roads countries belong to the community with Japan and China as the core. The Silk Roads countries are generally net receivers of carbon dioxide emission transfer in the network, and the volume is constantly expanding. In 2015, the inflow of carbon dioxide emission transfer was mainly distributed in Southeast Asian countries and core countries in other sub-regions, such as India in South Asia, Saudi Arabia in West Asia, Kazakhstan in Central Asia, Ukraine, and Belarus in Central and Eastern Europe.

From a spatial perspective, the sources of carbon dioxide emission transfer to the Silk Roads countries are mainly large developing countries such as China, Russia, and India, and developed countries such as the United States, Japan, and Germany. From 1997 to 2009, the United States has been the country that transferred the most carbon dioxide emissions to the Silk Roads countries. After 2010, China surpassed the United States and became the country that transferred the most carbon dioxide emissions to the Silk Roads countries. From the product level, the Silk Roads countries accepted the
transfer of carbon dioxide emission mainly in the industrial sectors of Electricity, gas and water, Petroleum, chemical and non-metallic mineral products, Transport, Mining and quarrying and Metal products. Compared with space, the transfer of carbon dioxide emission to the Silk Roads countries shows a higher degree of concentration at the industrial level.

6 Policy Implications

Based on the quantitative results, we summarize four aspects of policy implications. First, in addition to China, the countries that transfer large amounts of carbon dioxide emission to the Silk Roads countries such as the United States, Japan, and Germany should also be responsible for carbon dioxide emission in the countries along the Silk Road. And from a historical perspective, from 1995 to 2015, the United States transferred the most carbon dioxide emission to the Silk Roads countries through global value chains. Therefore, it is far from enough to just focus on China’s carbon dioxide emission transfer to the Silk Roads countries. The other countries, such as the United States, Japan, and Germany, should also take responsibility and actively reduce carbon dioxide emission transfer to the Silk Roads countries.

Second, while the construction of the BRI brings economic growth to the Silk Roads countries, the carbon dioxide emission will inevitably increase due to industrialization. However, the BRI should not be rejected because of this. We should spend more energy to explore how to increase the income of countries along the route and improve the living standards of their people while reducing carbon as much as possible by setting carbon dioxide emission standards and transferring low carbon dioxide emission technology.

Third, the carbon dioxide emission transferred to the Silk Roads countries through the global value chain shows a high degree of concentration in both space and products. These countries mainly include China, the United States, Japan, and Germany, while the industrial sectors mainly concentrated on Electricity, gas and water, Petroleum, chemical and non-metallic mineral products, Transport, Mining and quarrying. More specifically, the industrial sectors with high carbon dioxide emission and their corresponding countries are Metal products and Electricity, gas and water of China, Electrical and machinery of Germany, Public administration of Japan, Electricity, gas and water of Russia, and Electrical and machinery, Financial intermediation and business activities, Public administration of the United States. Targeted policies should be made for these countries and industry sectors to reduce these large sources of carbon dioxide emission transfer.

Finally, in future investment in countries along the Silk Road, China should focus more on eco-friendly industries, promote local economic development while disseminating low-carbon technologies, which will help promote the development of a global low-carbon economy. After the COVID-19 pandemic, China’s investment in thermal power in countries along the Silk Road has been on the rise, which will bring some resistance to carbon emissions reduction in countries along the Silk Road. In future power cooperation, it is necessary to further improve power generation technology to increase the power generation per unit of carbon emissions. At the same time, China has a well-developed photovoltaic industry, with powerful industrial clusters such as the Changzhou-Wuxi photovoltaic industry cluster, and international leading photovoltaic companies such as Suntech Power Co., Ltd and Trina Solar Co., Ltd. China should actively export clean energy power generation facilities to countries along the Silk Road to partially replace thermal power.

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