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The transfer of embodied carbon in copper international trade: An industry chain perspective

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ABSTRACT

The rapid development of the international mineral trade has provided a solid material foundation for economic developments worldwide. Accompanying mineral international trade, there is a huge amount of carbon emission transferred from importing countries to exporting countries, which masks the true distribution of global carbon emission and blurs the lines about the responsibility for preserving the environment. Aiming to explore the embodied carbon emissions, we construct an embodied carbon emissions network of copper concentrates and refined copper international trade (ECCR) for each year during the sample period from 2007 to 2014. We analyze structure features of ECCR international trade. There exists a large amount of potential transfer of carbon emissions. The external dependency on copper concentrates of China is not so high. The trade volume shows that China, Germany and the United States are net importers, Chile, Peru and Zambia are net exporters. Moreover, the trade volumes of main countries change within a narrow range. Considering that the changes of ECCR international trade, energy policies or emergencies are main factors to resources-oriented countries, sudden global economic events are main factors to importers. Combined with the economy of every country, we also analyze the embodied carbon intensity, which are significantly different of distinct type's countries. Furthermore, the evolution rule of embodied carbon intensity of some developed countries is similar to some developing countries.

1. Introduction

Copper concentrate and relevant products are the essential driving forces of the economy. Due to an imbalanced resource distribution, growing demand for mineral resources and relevant products, driven by their consumption, has increased the international trade. While the trade associated with copper concentrate and products is supported by mining and smelting processes (Li, 2015). Such processes not only consume natural resources, but also result in millions of tons of greenhouse gas emissions, particularly carbon dioxide (CO_2) (Li, 2010; Yin and Cheng, 2010; Matthias, 1998; Bi et al., 2011; Cansino et al., 2016; Lan et al., 2016). Naturally, when a country exports copper products to other countries, it also drives embodied carbon emissions in those products. Therefore, the embodied carbon emissions are contained in final production in a given country, which will be transferred to final consumption (Chen and Zhang, 2010; Clarke-Sather et al., 2011). However, due to the difference of economic structures and technology in different countries (Chaoxian, 2011; Reitler et al., 1987), the developing countries usually take the roles of main exporting countries with high energy consumption and pollution. They carry more of the burden of reducing carbon emissions. Meanwhile, the obvious "domestic emissions and foreign consumption" pattern frees importing countries from the obligation of environmental conservation (Bednar-Friedl et al., 2012; de la Rue du Can et al., 2015). All these facts could lead to an imbalance of international trade and economic development. Thus, it is important to uncover the embodied carbon emissions in international trade for clarifying carbon reduction responsibility.

The literature abounds with aggregate analyses of environmental issue, which enhances our understanding of embodied carbon transfer. For example, according to the research (Wyckoffa and Roopb, 1994) of six Organization for Economic Co-operation and Development (OECD) member states (Canada, France, Germany, Japan, the United Kingdom and the United States), accompanied with manufactured goods international trade, the embodied carbon imports accounted for 13% of its total emissions in the mid-1980s. Ahmad and Wyckoff (2003) also found that some OECD countries transfer large amount of embodied carbon, occupying about 50% of the total emissions. In addition, the

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OECD has reported the potential of environmental taxation to address the externality problem linked to CO_2 emissions (OECD, 2011).

So far, the life cycle assessment and input-output analysis (IOA) are widely used to study carbon emissions, especially the low-carbon emissions reduction policy of intra-regional trade and bilateral trade (Machado et al., 2001; Mongelli et al., 2006; Schaeffer and Leal De Sa, 1996; Tian and Jin, 2012; Wang et al., 2005). Furthermore, increasing studies find that the carbon leakage (Caron, 2012; Bednar-Friedl et al., 2012) and foreign investment (Tang and Tan, 2015) may make research results on untrue carbon emissions (Wang and Wei, 2014; Wang et al., 2014; Wiedmann, 2009; Zhou et al., 2013). Meanwhile, international trade involves a large number of countries and intricate trading linkages, which could be considered as a complex system. Complex network theory provides a method to analyze the embodied carbon transfer in international trade (An et al., 2014; Cao et al., 2006; Tian and Jin, 2012; Zhong et al., 2014). Nevertheless, quite a few scholars study the embodied carbon transfer of minerals in international trade by complex networks, especially combining some stages of an industrial chain. Therefore, we could use complex network theory to illustrate embodied carbon emissions.

In order to pave the way for balanced and sustainable resource exchanges and clarify who is responsible for environmental preservation, it is necessary to study the flow direction and intensity of embodied carbon transfer. To the best of our knowledge, this study is the first to introduce the industry chain to embodied carbon transfer of the international trade. An embodied carbon emissions of copper concentrates and refined copper international trade (ECCR) model is developed, combined with production of copper concentrates and refined copper, which are two important stages in the copper industry chain. From the perspective of industry chain, we could analyze the embodied carbon transfer of international trade systematically, and optimize product structure and trade structure preferably as a whole.

This paper is structured as follows: Section 2 introduces the data and model; Section 3 explains the main results; Section 4 presents the conclusions and policy implications.

2. Data and method

2.1. Data

Data of concentrates and refined copper trade come from the UN Comtrade data base for the 2007–2014 period, involving import and export flows among around 200 countries. Each type of copper products has a code in terms of HS code. The HS codes of copper concentrates and refined copper in the database are respectively 2603 and 7403. Copper products are represented by 7405, 7407, 7408, 7409, 7410, 7411, 7412, 7415, 7418 and 7419. In addition, each country has an international ISO country code.

2.2. Method

2.2.1. The calculation of embodied carbon emissions

A model is developed to calculate the embodied carbon emissions in international trade. Several indexes are introduced into this model: energy consumption standard required for producing ECCR, the coefficient of carbon emissions and the trade volumes of ECCR (Su et al., 2013; Xiao, 2010; Zhang et al., 2014). The functions are given as follows:

$$\mathrm{LCN} = \frac{(IN_N - EN_N)*\mathrm{M}*\mathrm{N}}{1000} \tag{1}$$

$$\mathrm{LCR} = \frac{(IN_R - EN_R)*\mathrm{M}*\mathrm{R}}{1000} \tag{2}$$

$$\mathrm{LCNW} = LCN+LCR \tag{3}$$

$$\mathrm{ECI} = \frac{\mathrm{LCNW}}{\mathrm{GDP}} \tag{4}$$

Where LCN refers to the net trade volume of copper concentrates. IN_N refers to the import volume of copper concentrates, and EN_N refers to export volume the copper concentrates. M is the coefficient of carbon emissions (0.73257), which is drawn from Oak Ridge National Laboratory. N is the energy consumption standard of producing copper concentrates (0.0163tce/t), which is drawn from GB YS/T693-2009. LCR refers to the net trade volume of refined copper. IN_R is the import volume of refined copper, and EN_R is the export volume of refined copper. R is the energy consumption standard of refined copper (0.420tce/t), which is calculated by GB 21248-2014. LCNW is the embodied carbon volume of copper concentrates and refined copper, which is a net value calculated by the trade of copper concentrates and refined copper. ECI is the embodied carbon trade intensity of copper concentrates and refined copper.

Furthermore, the production of copper concentrate and production of refining are important stages of copper industry chain. Carbon emissions of these two stages are dependent on the direct or indirect source of energy used in those stages. Briefly, diesel (for trucks and mining equipment) and electricity are used in mining (copper concentrate production) stage (open cuts typically consume less electricity than underground). Coking coal and natural gas are the main energy sources in smelting. Electricity and natural gas are used in fire refining (refined copper production), and electricity is the main energy source used in electro-refining (Davenport et al., 2002). Moreover, the technologies used to produce copper are different among countries, and these technologies are associated with different emissions. However, 80% of the world's primary copper is produced by pyrometallurgical, and about 20% is produced by hydrometallurgical. Therefore, the difference caused by the pyrometallurgical technology is subtle, and the main variation among countries possibly is reflected on electricity generation technologies in the course of electro-refining.

Concerning the electricity generation, we explore the energy sources. Table 1 shows Australia, Germany, India, Indonesia, United States, Japan, Mexico and China （group1） mainly use fossil-energy, whereas Chile, Canada, Zambia and Peru (group 2)utilize a large amount of nuclear or hydroelectric resources. Therefore, there is little difference among the same group.

2.2.2. Complex network model

The main idea of complex network theory is to consider the relationships among various parts of real complex systems as a complex network. The complex network model provides an innovative perspective to explore and analyze the complex systematic phenomena and structural characteristics based on a many-to-many node-edge relation. The complex network model G=(V, E) contains the nodes V and the edges E, where V ={v_i:i=1, 2, ..., n}, and n is the number of nodes; E ={e_i:i=1, 2, ..., m}, and m is the number of edges.

We construct an ECCR model. In our model, the nodes are the countries; the edges are the trade relationships; the directions of the edges are the directions of the embodied carbon transfer flows; and the weights of the edges are the value of embodied carbon. The real ECCR network is composed of numerous countries and trade relationships, thus there are thousands of exporting and importing relationships. If country i exports embodied carbon to country j during year t, then the edge representing the trade relationship from i to j is drawn and $a_{ij}(t)$ =1. Otherwise, no edge is drawn and $a_{ij}(t)$=0. If there is a relationship between i and j, the volume of embodied carbon transferred from country i to country j is denoted as w_{ij}. Fig. 1 shows the embodied carbon emissions net trade network in 2014.

The definitions and formulations of some indicators in complex network theory are introduced combined with the study issue in this paper.