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Analysis

Inter-industrial Carbon Emission Transfers in China: Economic Effect and Optimization Strategy

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ABSTRACT

Understanding inter-industrial carbon emission transfers and their economic effect informs approaches to achieve emission reduction objectives and promote industrial economic development. This paper applies input-output theory to explore ways to optimize carbon emission transfers between industrial sectors. First, China's inter-industrial carbon emission imports and exports were measured for years 2002, 2005, 2007, and 2010. Next, the economic effects of inter-industrial carbon emission transfers were assessed. Finally, strategies to optimize the carbon emission transfer structure were proposed, with the goal of achieving a win-win between industrial carbon emission reduction and economic development. Key study conclusions are as follows. (1) Inter-industrial carbon emission imports and exports in China are significant, and are increasing each year. Traditional energy industries have high carbon emission imports; processing and manufacturing industries have high carbon emission exports; and most light industries have relatively low levels of both carbon emission imports and exports. (2) Carbon emission transfer imports or exports can promote industrial development; combining both imports and exports leads to variable economic effects within specific industries. (3) To achieve the dual goals of carbon emission reduction and economic development, four strategies are proposed to optimize carbon emission transfer structures in different industries.

1. Introduction

In 2007, China emitted 6.05 billion tons of CO_2, more than any other country. This emissions level accounted for 24.35% of total worldwide carbon emissions (International Energy Agency, 2009). However, China's annual CO_2 emission transfer has reached 1.2 billion tons, or almost 20%, of total carbon emissions (Guan and Refiner, 2010). Deducting these transferred CO_2 emissions from the total dramatically reduces China's CO_2 emissions. The international community currently accounts for carbon emissions at a country or regional level using a producer responsibility system. This method does not consider the influence of inter-region carbon emission transfers introduced by inter-country or inter-regional commodity trade (Eder and Narodoslawsky, 1999; Pedersen and de Haan, 2006; Peters et al., 2011). The result is an unfair distribution of responsibilities for carbon emission reduction (Whalley and Walsh, 2009; Stern, 2007).

Accurately accounting for China's carbon emissions would more clearly define China's responsibility for reducing carbon emissions, and effectively reduce global emissions. To this end, many scholars have studied China's carbon emission transfers (Shui and Harriss, 2006; Su and Ang, 2014; Chen, 2009). There are three types of transfers: inter-country carbon emission transfers, inter-provincial carbon emission transfers, and inter-industry carbon emission transfers.

Shui and Harriss (2006), Xu et al. (2009), Yu and Wang (2010), and Guo et al. (2012) focused on inter-country carbon emission transfers by studying transfers embodied in China-United States (U.S.) trade. These studies found that 7–14% of China's CO_2 emissions resulted from commodity exports to the U.S. Li and Hewitt (2008) studied the carbon emissions embodied in China-British trade, concluding that in 2014, 186 million tons of CO_2 was embodied in product exports from China to Britain, accounting for 4% of China's total carbon emissions. Liu et al. (2010) and Wu and Li (2012) also analyzed the carbon emission transfers embodied in China-Japan trade, noting that trade increased China's total carbon emissions and promoted its overall economic growth. Wang and Watson (2007), Wei et al. (2011), Lin and Sun (2010) evaluated China's carbon emission transfers as part of its overall foreign trade, concluding that China had become a net exporter of embodied carbon emissions, with net exports accounting for approximately 14.4% of total carbon emissions.

Turning to inter-provincial carbon emission transfers, Su and Ang (2010) analyzed China's embodied transfers, highlighting the need to consider differences among different China's provinces. Based on

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China's 1997 inter-regional input-output table, Yao and Liu (2010) and Su and Ang (2014) calculated the total transfer and flow characteristics of embodied carbon emissions among China's eight major regions. Meng et al. (2011) found that embodied carbon emission transfers, based on energy products, have continuously increased from eastern to central and western China since 2003, especially in the central provinces.

Feng et al. (2013) found that 57% of China's emissions related to goods consumed outside of the originating province. For example, up to 80% of the emissions related to goods consumed in highly developed coastal provinces, but imported from less developed central and western provinces, which produce many low–value-added but high–carbon-intensive goods. Zhang et al. (2014a, b) compared the scale of CO_2 emissions, emissions growth rate, emissions intensity, and other indices for different provinces over several years, examining the CO_2 emissions of different Chinese provinces between 1990 and 2011. The study identified a number of inter-provincial transfers with different CO_2 emission scales and intensities, and with different regional and stage characteristics. Zhang et al. (2014a, b) dynamically analyzed CO_2 emission inter-regional transfers, finding that CO_2 emissions embodied in inter-provincial trade sharply increased between 2002 and 2007. Sun et al. (2016) analyzed the carbon emission transfer characteristics of 30 China provinces in 2007, calculating the economic spillover and emission reduction effects of inter-provincial carbon emission transfer.

Turning to China's inter-industrial carbon emission transfers, Chen (2009) calculated the embodied carbon emissions consumed by different sectors in China in 2002. The construction industry generated the most embodied carbon emissions, and the non-metallic mineral products sector has the highest proportion of embodied CO_2 emissions from industrial process. Xu and Zou (2010) analyzed the indirect effects and transfer mechanisms of embodied carbon emissions during production and consumption for 27 industrial sectors. Su et al. (2010) applied an input-output analysis framework to analyze China's sector aggregation effects to estimate the CO_2 emissions embodied in the economy's exports.

These studies provide useful information, but have limitations. First, while they analyze China's overall and inter-provincial carbon emission transfers, few consider inter-industrial carbon emission transfers. Further, the studies mainly focus only on a single year, rather than a longer-term dynamic view. Second, these studies analyze the amount and role of carbon emission transfers, but not the inter-industrial carbon emission transfer economic effects. Third, these studies mainly focus on determining responsibility for carbon emission reduction by considering carbon emission transfers, but few look for a win-win balance of carbon emission reduction and economic development.

To complement this previous work, this study used input-output tables from 2002, 2005, 2007, and 2010 to analyze the total amount and changing dynamics of inter-industrial carbon emission transfers in China, and how they influence industrial economic development. The study also adopted China's 2020 carbon emission reduction objective, proposing strategies to achieve a win-win between industrial carbon emission reduction and economic development, while optimizing the carbon emission transfer structure.

2. Methodology and Data

2.1. Carbon Emission Transfer Measurement Model

Carbon emission transfer is similar to carbon leakage; when one country or region implements rigorous emission reduction policies, emissions increase in other countries or regions (Reinaud, 2008). Generally, carbon emission transfers consist of two dimensions: imports and exports (Sun et al., 2016). Inter-industrial carbon emission imports refer to the transfer generated by the flow of commodities from external industries into a different industry. Here, external industries generate carbon emissions during the commodity production process; those commodities are then consumed by a different industry. Carbon emission exports refer to the transfer generated when commodities flow from one industry into other external industry. Here, one industry's commodity production processes generate emissions, but the commodities are consumed by external industries.

Previous studies adopted an input-output method to measure carbon emission transfers (Wiedmann et al., 2007; Peters and Hertwich, 2008; Wiedmann, 2009; Andrew and Forgie, 2008; Miller and Blair, 2009; Su and Ang, 2011; Su et al., 2013; Su and Ang, 2014 and others). As the input-output structure of Table 1 shows, the number in Quadrant I represents intermediate inputs. This number reflects the mutual provision of services and products among different sectors in the national economy for production and consumption. The y-axis represents the total products and services from different output sectors consumed by the production sectors; the x-axis represents the products and services the output sectors provide to other sectors for intermediate consumption.

Using these definitions of inter-industrial imports and exports, this paper defines the industrial sector's carbon emission imports (CEI) as the carbon emission transfer generated by the products and services of other industrial sectors, consumed by the vertical industrial sectors. The input-output table further defines the carbon emission transfer generated by the products and services of the horizontal output sectors; these are intermediately consumed by other production sectors. These are the industrial sector's carbon emission exports (CEE).[1] Eqs. (1)–(7) use the input-output model (Leontief, 1970) and the carbon emission coefficient method (He, 2012) to calculate the inter-industrial carbon emission transfer.

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \tag{1}$$

In the standard input-output model, Eq. (1) expresses the total output of the ith sector. Here, x_i represents the total output of the industrial sector, i; x_{ij} represents the intermediate input by the sector i into the products of the sector j. The variable y_i represents the ultimate demand for the products of the sector i.

$$\alpha_{ij} = x_{ij}/x_j \tag{2}$$

In Eq. (2), α_{ij} represents the intermediate consumption coefficient of sector i products by unit output of sector j ($0 \le \alpha_{ij} < 1$).

Substituting Eq. (2) into Eq. (1) yields:

$$x_i = \sum_{j=1}^{n} \alpha_{ij} x_j + y_i \tag{3}$$

Converting Eq. (3) into a matrix form results in Eq. (4):

$$X_t = A_t X_t + Y_t \tag{4}$$

In Eq. (4), X_t, A_t and Y_t represent the total output matrix, intermediate input coefficient matrix, and ultimate demand matrix, respectively, of the horizontal industrial sectors.

Eq. (4) can be rewritten as:

$$X_t = (I - A_t)^{-1} Y_t = L_t Y_t \tag{5}$$

In Eq. (5), $L_t = (I - A_t)^{-1}$ is a Leontief inverse matrix. It represents the demand that the horizontal industrial sectors have for the input industrial sectors' products. Assuming that F_t represents the vector of the CO_2 emissions per unit output of the horizontal

[1] Given that this study focused on the internal industrial sectors in China, it does not consider trade relations, and therefore did not calculate the carbon emission transfers generated by trade between China's industrial sectors and other countries.