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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 ($0 \leq \alpha_{ij} < 1$).

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.

Table 1
Structure of input-output table.

Input \ Output		Intermediate consumption				Ultimate consumption											Imports	Total Outputs
		Sector *1*	…	Sector *n*	Total	Ultimate consumption					Gross capital formation			Exports	Ultimate Consumption Total Amount			
						Household consumption			Government's Consumption	Total Amount	Fixed Capital Formation	Inventory Increase	Total Amount					
						Rural Residents' Consumption	Urban Residents' Consumption	Subtotal										
Intermediate Inputs	Sector *1*	Quadrant I				Quadrant II												
	…																	
	Sector *n*																	
	Total																	
Added Value	Remuneration for workers	Quadrant III																
	…																	
	Total																	
	Total input																	

industrial sector, Eq. (6) expresses the CO_2 vector C of the industrial sector (Su and Ang, 2010).

$$C = F_t'X_t = F_t'(I - A_t)^{-1}Y_t = F_t'L_t(Y_{dd} + Y_{de}) \tag{6}$$

In Eq. (6), $Y = Y_{dd} + Y_{de}$, Y_{dd} represents the ultimate demand vector of the industrial sector and Y_{de} represents the industrial sector's output vector.

Eq. (6) yields the CEE vector C_{ee} of the industrial sector:

$$Cee = F_t'(I - A_t)^{-1}Y_{de} = F_t'L_tY_{de} \tag{7}$$

Similarly, the vertical direction of the input-output table allows the CEI vector C_{ei} of the industrial sector to be derived.

$$C_{ei} = F_l'(I - A_l)^{-1}Y_{di} = F_l'L_lY_{di} \tag{8}$$

In this expression, Y_{di} represents the import vector of the vertical industrial sector.

Eqs. (7) and (8) demonstrate that calculating industrial sector carbon emission imports and exports also requires us to calculate the carbon emission coefficients of different industrial sectors, that is, the carbon emission vectors per unit output. An industrial sector's carbon emission coefficient mainly consists of the direct carbon emissions per unit output (direct carbon emission coefficient) and the indirect carbon emissions per unit output (indirect carbon emission coefficient). These are calculated using Eqs. (9)–(10) (He, 2012).

$$c_i = \sum_{k=1}^{n} \beta_{ik}q_{ik} + \sum_{j=1}^{m} x_ib_{ij}f_j \tag{9}$$

In Eq. (9), c_i represents the total amount of carbon emissions of industrial sector i; $\sum_{k=1}^{n} \beta_{ik}q_{ik}$ represents the direct carbon emissions of the industrial sector i. The variable q_{ik} represents the amount of the kth energy consumed by the industrial sector i, and β_{ik} represents the carbon emission coefficient of the kth energy.[2] The expression $\sum_{j=1}^{m} x_ib_{ij}f_j$ represents the indirect carbon emissions of the industrial sector i, where x_i represents the total outputs of the industrial sector i, b_{ij} represents the complete consumption coefficient of j by the industrial sector i. The matrix form of this is derived from Eq. (5), i.e., $B = (I - A_t)^{-1} - I$). The term f_j represents the carbon emission intensity of the industrial sector j. The carbon emission coefficient of the industrial sector i is:

$$f_i = c_i/x_i \tag{10}$$

Calculating CEI and CEE yields the industrial net carbon emission transfer (NCE), using Eq. (11) (Sun et al., 2016).

$$NCE = CEI - CEE \tag{11}$$

The NCE represents the carbon emission transfer characteristics of an industrial sector, with the combined actions of imports and exports. When the industrial net carbon emission transfer exceeds zero, the CEI of the industrial sector exceeds the CEE. This suggests that the industrial sector has transferred carbon emissions to other industrial sectors, resulting is less responsibility for carbon emissions than assumed by most models.

2.2. Modeling the Economic Effect of the Carbon Emission Transfer

Carbon emission transfers are reflected in economic development, transformation, and evolving industrial demands. As such, inter-industrial carbon emission transfers influence assigned responsibilities for carbon emissions and their reduction, as well as

[2] The specific numerical values were derived from Intergovernmental Panel on Climate Change (IPCC) 2006.

industrial economy development (Whalley and Walsh, 2009). Eq. (12) calculates the overall economic effect of inter-industrial carbon emission transfers.

$$Y_{it} = \alpha + \beta_1 CEI_{it} + \beta_2 CEE_{it} + \varepsilon_{it} \quad (12)$$

In this equation, CEI_{it} and CEE_{it} represent carbon emission imports and exports, respectively, of industry i in the tth year; Y_{it} represents the added value of industry i in the tth year; β_1 and β_2 represent the economic outputs created per unit carbon emission import and export, respectively; α is the intercept term, representing industrial economic development without the effect of carbon emission transfer; and ε_{it} is the stochastic error.

Eq. (12) is converted into Eq. (13) to quantify the economic effects of different industrial sector carbon emission transfers in different years. The calculation assumes the coefficients of different explanatory variables can change.

$$Y_{it} = \alpha_{it} + \beta_{it} CE_{it} + \sigma_{it} \quad (13)$$

In this equation, CE_{it} represents the carbon emission transfer of industry i in the tth year. CE_{it} can be expressed for three factors: carbon emission imports (CEI), carbon emission exports (CEE), and net carbon emission (NCE). The variable β_{it} represents the economic effect of carbon emission transfers from industry i in the tth year; α_{it} is the intercept term and has the same economic meaning as α; and σ_{it} is the stochastic error.

2.3. Industry Selection and Data Source

In China's industrial structure, secondary and tertiary industries lead economic development; their cumulative values account for approximately 45.73% and 44.16% of China's gross domestic product (GDP), respectively. In the input-output table, the secondary industry includes 23 industrial sectors and the construction industry. The total energy consumption of these 24 sectors accounts for approximately 71.5% of the nation's energy consumption.

For tertiary industries, the transportation and warehouse industry, the wholesale and retail trade industry, and the accommodation and catering industry together account for approximately 36.19% of the total national value, and approximately 41.60% of the tertiary industry's total energy consumption (National Bureau of Statistics of China (NBSC), 2014). As such, these three industrial sectors represent significant economic and carbon emission output sectors.

Based on this analysis, this study focused on the 27 (24 + 3) sub-industries listed in Table 2. These major industries consume energy, emit CO_2, and support China's economic development. Studying these industries provides insights about the total amounts, dynamic characteristics, and economic effects of inter-industrial carbon emission transfers across China. Inter-industrial data in this paper are derived from *China's input-output tables* from 2002, 2005, 2007, and 2010. Industrial added value data for Eqs. (12) and (13) are from the *Chinese Industrial Statistics Yearbook,* 2003 to 2014.

3. Empirical Study

3.1. Carbon Emission Transfer Characteristics

Eqs. (7)–(11) were used to calculate China's inter-industrial carbon emission imports (Fig. 1), carbon emission exports (Fig. 2), and net carbon emission transfers in 2002, 2005, 2007, and 2010. These equations analyzed two characteristics of inter-industrial carbon emission transfers: total amount and dynamic change.

3.1.1. Total Amount Characteristics

Traditional energy industries have relatively high carbon emission imports, whereas processing and manufacturing industries have high carbon emission exports. Fig. 1 shows that the five largest industries for total carbon emission imports are OGE, MMI, PPCN, EHPS, and CMWI. These industries are energy and resource-related, representing the national economy's traditional and leading heavy industry sectors. Energy industries consume many terminal products from other industries, but generate only a few terminal products themselves, mainly energy-related. As such, energy industries have high carbon emission imports, manifested as a positive net carbon emission transfer.

In contrast to energy industries, CTI, GSEM, EMEM, MPI, and MSRP have relatively low carbon emission imports, but are the five largest industries for carbon emission exports. These are processing and manufacturing industries; their terminal products mainly serve the development of other industries. As such, processing and manufacturing industries have relatively high carbon emission exports, with a negative net carbon emission transfer.

More specifically, we found that CTI has the largest negative net carbon emission transfer, a finding consistent with Chen (2009). CTI is an independent and complete material production sector, with final products consisting of mainly fixed assets. These assets serve as materials for other industrial sector's production needs. Because CTI provides many terminal products to the market, it generates relatively high carbon emission exports.

Figs. 1 and 2 show that light industries, GPSI, WPSI, TI, CLII, WPFM, and others, have relatively low carbon emission imports and exports. These industries have relatively low total outputs, low total energy consumption, and minimally influence other industries.

Table 2
Studied industrial sectors.

No.	Industrial sector	Abbreviation	No.	Industrial sector	Abbreviation
1	Coal mining and dressing	CMWI	15	General and special equipment manufacturing	GSEM
2	Petroleum and natural gas extraction	OGE	16	Transportation equipment manufacturing	TEMI
3	Metals mining and dressing	MMI	17	Electric equipment and machinery	EMEM
4	Nonmetal mineral mining and dressing	NMMI	18	Communication equipment, computer and other electronic equipment manufacturing	CECE
5	Food production and tobacco processing	FMTP	19	Instruments, meters, cultural and office machinery	MMII
6	Textile industry	TI	20	Other manufacturing industries and waste resources and materials	OMW
7	Clothing, leather, furs, down and related products	CLII	21	Electric power and hot power production and supply	EHPS
8	Timber processing and furniture manufacturing	WPFM	22	Gas production and supply	GPSI
9	Papermaking, printing and cultural, educational and sports goods	PPSM	23	Water production and supply	WPSI
10	Petroleum processing, coking and nuclear fuel processing	PPCN	24	Construction industry	CTI
11	Chemicals	CI	25	Transportation and warehousing	TW
12	Nonmetal mineral products	NMMP	26	Wholesale and retail trade	WRT
13	Metal smelting and rolling	MSRP	27	Accommodation and catering	AC
14	Metal products	MPI			

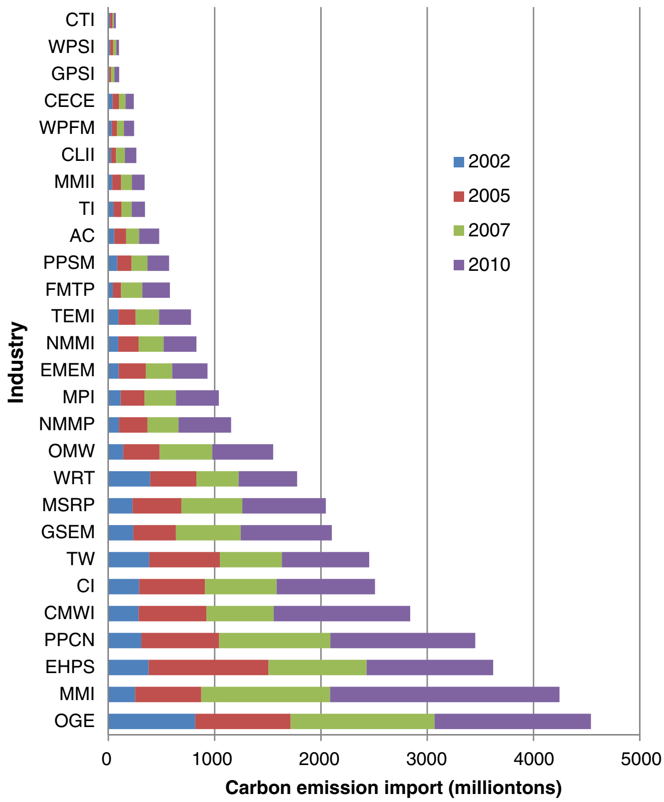

Fig. 1. Inter-industrial carbon emission imports between 2002 and 2010.

3.1.2. Dynamic Change Characteristics

Industrial carbon emission imports and exports increased over time, with average growth rates of 15.75% for imports and 13.78% for exports.

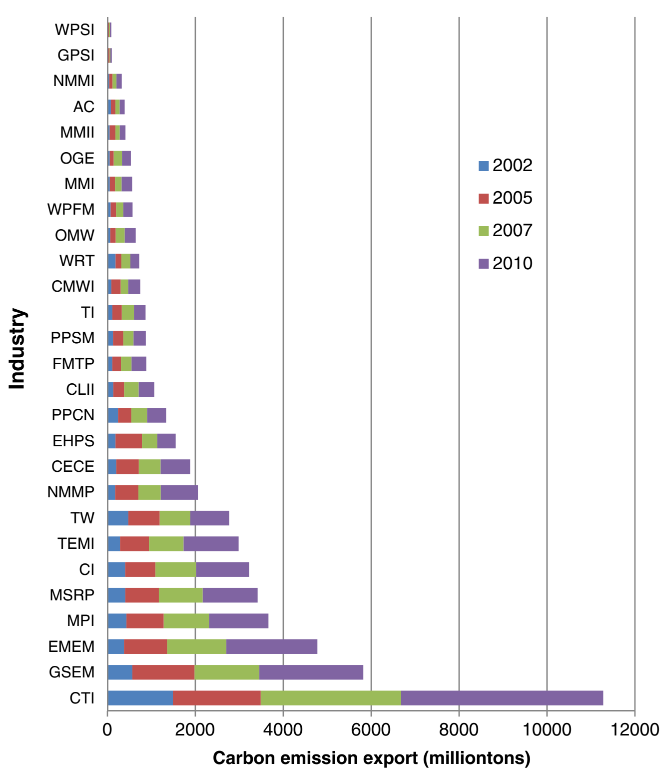

Fig. 2. Inter-industrial carbon emission exports between 2002 and 2010.

To be specific, imports and exports were 24.41% and 24.27%, respectively, between 2002 and 2005; 11.88% and 7.06% between 2006 and 2007; and 10.97% and 10.00% between 2008 and 2010. Industrial carbon emission imports and exports grew significantly, particularly during China's rapid economic growth before 2006; the speed of growth declined after 2006.

China faces increasing pressure from home and abroad to reduce carbon emissions. In response, the Chinese government launched a series of specific carbon emission reduction measures. These include the *Implementation Scheme of Monitoring System of Energy Consumption per Unit GDP* established by National Development and Reform Commission (NDRC) and other departments in 2007; and the *Measures for Administration of Industrial Energy Conservation established by the Ministry of Industry and Information Technology* in 2008. The Chinese government also proposed a carbon emissions reduction plan at the Copenhagen Climate Conference in 2009. These policies have reduced the growth of industrial sector carbon emissions, and have motivated some high-energy consumption and high-emission industries to accelerate carbon transfers to other industries.

The average annual growth rates of industrial carbon emission imports and exports were positive, but differed across specific industries (Fig. 3). Eight industries (OGE, CI, TEMI, EMEM, CECE, WPSI, CTI, and WRT) experienced lower growth rates in carbon emission imports than exports. These industries have accepted more carbon emission transfers from other industries, taking on greater responsibility for reducing emissions, and conflicting with the goal of reducing them.

In contrast with these eight industries, the remaining 19 industries (CMWI, MMI, NMMI, FMTP, TI, CLII, WPFM, PPSM, PPCN, NMMP, MSRP, MPI, GSEM, MMII, OMW, EHPS, GPSI, TW, and AC) experienced more growth in carbon emission imports than exports. These industries generally transferred carbon emissions to other industries, also transferring emission reduction responsibility.

3.2. Economic Effect of Industrial Carbon Emission Transfer

3.2.1. Overall Economic Effect

Table 3 presents the relevant parameters calculated in Eq. (12), estimated using Eviews 8.0 software. The *p*-values and *t* statistics of all parameters passed statistical tests at a significance level of 0.01 (an F statistic of 104.3314). This indicates that the model was overall statistically significant, and that the estimated coefficient values were valid.

The coefficients of industrial carbon emission imports and exports in Table 3 were positive (0.0359 for imports; 0.0452 for exports). This suggests that both imports and exports promoted industrial economic development, creating positive economic effects. In other words, inter-industrial carbon emission transfers align with China's current industrial development policies, and have positively influenced industrial economic development. Based on the intensity of influence, the coefficient for industrial carbon emission exports (0.0452) exceeded the coefficient for imports (0.0359). This suggests that industrial carbon emission exports have a greater economic impact than imports, and increasing exports impacts the industrial economy more.

3.2.2. Industrial Differences of Economic Effects

Table 4 presents the relevant parameters calculated in Eq. (13), again estimated using Eviews 8.0 software. The results were similar to those in Table 3; all coefficient values passed tests of statistical significance. For these tests, however, the significance level was set at 0.05, a higher level than for previous tests. The estimated coefficients are statistically credible.

Table 4 lists the influences of CEI and CEE, and the combined influence of imports and exports on the economic development of various industries. As the specific coefficients show, increasing carbon emission imports or exports increases economic output. Usually, industrial economic development is jointly influenced by carbon emission

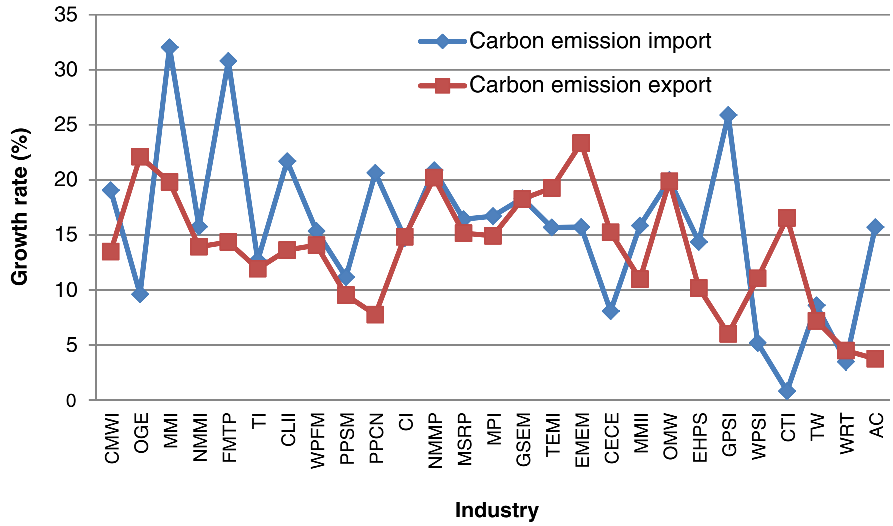

Fig. 3. Average growth rates of industrial carbon emission imports and exports.

imports and exports; the economic effect is reflected in the industrial net carbon emission transfer coefficient β.

Eight industries (CMWI, OGE, MMI, NMMI, PPCN, OMW, EHPS and WRT) experienced positive economic effects from industrial net carbon emission transfers; these industries benefited from high industrial net carbon emission transfers and a wider margin of carbon emission imports over exports. These conditions benefit these industries' economic development. If promoting industrial economic development is the goal, then these industries' CEI should be increased.

Fifteen industries (FMTP, TI, CLII, WPFM, PPSM, CI, NMMP, MSRP, MPI, GSEM, TEMI, EMEM, CECE, CTI, and TW) experienced negative economic effects from industrial net carbon emission transfers; these industries would benefit from a decline in net carbon emissions. The data suggest that a wider margin of carbon emission exports over imports could significantly benefit the development of these 15 industries. Appropriately increasing their carbon emission exports should help increase economic output.

Four industries (MMII, GPSI, WPSI, and AC) experienced ambiguous economic effects from emission transfers; the coefficient β was positive in some years and negative in others. GPSI and AC industries both experienced positive economic effects of net carbon emission transfers in 2007 and 2010. A wider margin of carbon emission imports over exports may benefit these two industries' economic development. MMII and WPSI industries experienced a positive economic effect of net carbon emission transfers in 2007 and a negative effect in 2010. This suggests that economic effects transitioned from being positive to negative. More data is needed to establish a trend, and point a path to economic development.

3.3. Optimizing Carbon Emission Transfer

A rational inter-industrial carbon emission transfer structure would help achieve industrial carbon emission reduction objectives, and promote industrial economic development. To that end, this section uses the analysis of emission transfer characteristics and economic effects to propose strategies to optimize industrial carbon emission transfer structure. These strategies maximize the dual objectives of reducing emissions and increasing economic development.

Table 3
Overall economic effect of carbon emission transfer.

Variable	Coefficient	Std. error	*t*-Statistic	*p*
α	21.3170	3.5808	5.9532	0.0000
β_1	0.0359	0.0059	6.0845	0.0000
β_2	0.0452	0.0035	12.9743	0.0000
R-squared	0.3940	Mean dependent var	56.7413	
Adjusted R-squared	0.3902	S.D. dependent var	53.6130	
F-statistic	104.3314	Durbin-Watson stat	0.8279	

The Chinese government proposed a quantifiable carbon emission reduction objective at the 2009 Copenhagen Climate Conference, stating: “By 2020, the CO_2 emissions per unit GDP (carbon intensity) will have been reduced by 40%–50% on the basis of 2005.” Achieving this goal requires meeting specific carbon emission reduction targets across different industries. With a common carbon intensity reduction goal of 45%, there must be an average annual reduction rate of 3.91% between 2005 and 2020.

To determine whether different industries can achieve the target, we compared the actual average reduction rates of 27 industries between 2005 and 2012 against the benchmark reduction rate. If an industry's actual reduction rate exceeds 3.91%, then the industry is positioned to achieve the reduction objective by 2020. If the rate is below the benchmark rate, the industry needs a new strategy to achieve the goal.

Based on the 45% emission reduction target, it appears that 14 industries can achieve the goal by 2020; the remaining 13 industries may not. To assess the influence of industrial carbon emission imports and exports on both emissions reduction and economic development, this study applied two rules to optimize the industrial carbon emission transfer structure.

Rule 1: If the target is likely to be met by an industry, then the current primary goal of those industrial economies will be adopted as the goal of the industrial carbon emission transfer structure.

Rule 2: If the target is not likely to be met by an industry, then reducing the industry's carbon emissions becomes the primary objective, before considering economic development.

Combining carbon intensity reduction rates across the different industries studied, and the influence of net carbon emission transfers on economic development between 2005 and 2012, this section proposes different strategies for four industry types to optimize inter-industrial carbon emission transfers (Fig. 4).

Type 1 includes eight industries (CMWI, OGE, MMI, NMMI, PPCN, OMW, GPSI, and WRT). All can achieve the carbon intensity reduction objective of 45% by 2020; their existing net carbon emission transfers create a positive economic effect, and their carbon emission imports and exports are assumed to rise over time. Thus, Rule 1 applies, and their economic output can be enhanced by increasing CEI and reducing exports.

Table 4
Economic effects of carbon emission transfer between 2002 and 2010.

Industry	β (CEI)				β (CEE)				β (NCE)			
	2002	2005	2007	2010	2002	2005	2007	2010	2002	2005	2007	2010
CMWI	0.08	0.05	0.07	0.07	0.26	0.15	0.26	0.34	0.12	0.08	0.10	0.09
OGE	0.03	0.04	0.04	0.05	0.45	0.43	0.30	0.34	0.03	0.05	0.05	0.05
MMI	0.02	0.02	0.02	0.02	0.12	0.09	0.15	0.16	0.03	0.02	0.02	0.02
NMMI	0.08	0.04	0.06	0.06	0.18	0.09	0.17	0.15	0.14	0.06	0.11	0.10
FMTP	1.08	0.93	0.51	0.55	0.40	0.37	0.42	0.42	−0.65	−0.61	−2.47	−1.89
TI	0.47	0.43	0.52	0.53	0.20	0.15	0.18	0.25	−0.34	−0.24	−0.27	−0.48
CLII	0.65	0.64	0.48	0.43	0.12	0.12	0.12	0.13	−0.15	−0.15	−0.16	−0.19
WPFM	0.36	0.27	0.40	0.30	0.15	0.11	0.16	0.14	−0.25	−0.19	−0.27	−0.25
PPSM	0.28	0.20	0.24	0.21	0.19	0.11	0.15	0.15	−0.55	−0.27	−0.42	−0.57
PPCN	0.03	0.03	0.04	0.04	0.04	0.08	0.10	0.14	0.15	0.05	0.05	0.06
CI	0.20	0.14	0.19	0.20	0.14	0.13	0.14	0.15	−0.51	−1.25	−0.51	−0.64
NMMP	0.19	0.16	0.21	0.18	0.11	0.08	0.12	0.10	−0.25	−0.16	−0.29	−0.25
MSRP	0.17	0.14	0.21	0.19	0.09	0.08	0.12	0.12	−0.21	−0.21	−0.28	−0.32
MPI	0.12	0.10	0.13	0.11	0.03	0.03	0.04	0.03	−0.04	−0.04	−0.05	−0.05
GSEM	0.16	0.15	0.15	0.16	0.06	0.04	0.06	0.06	−0.11	−0.06	−0.11	−0.09
TEMI	0.27	0.23	0.29	0.37	0.09	0.06	0.08	0.09	−0.13	−0.08	−0.11	−0.12
EMEM	0.18	0.13	0.19	0.22	0.05	0.03	0.03	0.04	−0.06	−0.05	−0.04	−0.04
CECE	0.69	0.74	1.10	1.12	0.14	0.09	0.14	0.13	−0.17	−0.10	−0.16	−0.15
MMII	0.12	0.10	0.10	0.12	0.08	0.06	0.11	0.11	−0.29	−0.17	2.43	−1.34
OMW	0.04	0.03	0.10	0.11	0.09	0.08	0.25	0.24	0.08	0.05	0.17	0.19
EHPS	0.10	0.06	0.10	0.09	0.21	0.10	0.25	0.26	0.20	0.12	0.15	0.14
GPSI	0.09	0.12	0.07	0.11	0.04	0.06	0.11	0.15	−0.08	−0.13	0.17	0.39
WPSI	0.17	0.15	0.18	0.31	0.23	0.19	0.26	0.24	0.68	0.76	0.63	−1.05
CTI	4.14	4.47	11.49	13.77	0.04	0.05	0.05	0.06	−0.04	−0.05	−0.05	−0.06
TW	0.18	0.16	0.25	0.23	0.14	0.15	0.21	0.21	−0.74	−2.19	−1.28	−2.98
WRT	0.24	0.31	0.44	0.56	0.50	1.03	0.84	1.51	0.45	0.45	0.90	0.88
AC	0.53	0.37	0.46	0.43	0.37	0.40	0.58	0.71	−1.17	4.44	2.24	1.06

Type 2 includes six industries (FMTP, NMMP, TEMI, GSEM, CTI and TI). All can achieve the carbon intensity reduction objective of 45% by 2020; but their existing net carbon emission transfers create a negative economic effect. Carbon emission imports and exports are both assumed to rise over time. According to Rule 1, promoting economic development is the primary objective. To reduce the negative economic effects of net carbon emission transfers, CEI should be reduced and CEE should be increased.

Type 3 includes 11 industries (CLII, WPFM, PPSM, CI, MSRP, MPI, EMEM, CECE, MMII, TW, and WPSI). None of these are projected to reduce carbon intensity by 45% by 2020. Further, their net carbon emission transfers have a negative economic effect, and their carbon emission imports and exports are progressively increasing. Based on Rule 2, the primary goal is to reduce industrial carbon emissions by increasing CEI. CEE can be subsequently increased to improve economic output.

Type 4 includes two industries (EHPS and AC), neither of which can achieve a carbon intensity reduction of 45% by 2020. However, their net carbon emission transfers create a positive economic effect, as carbon emission imports and exports were both positive. Based

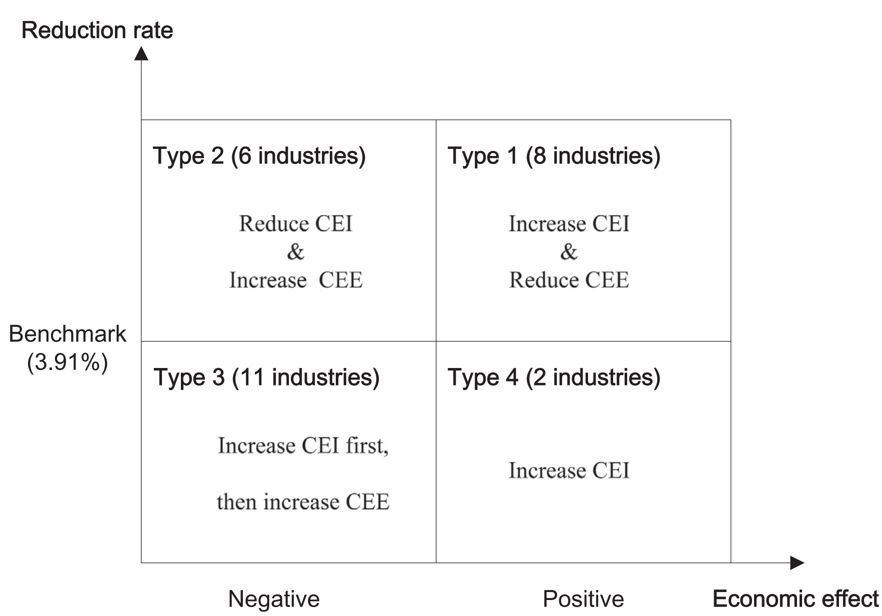

Fig. 4. Optimization strategies for carbon emission transfer.

on Rule 2, carbon emission reduction objectives can be realized by increasing carbon emission imports. Carbon emission imports can be subsequently increased to promote economic development.

4. Conclusions and Policy Implications

Concurrently promoting industrial economic development and realizing carbon emission reduction goals are vital for building a sustainable economy for China. Both factors serve as a solid foundation for industrial carbon emission transfer structures. Based on this, this study analyzed the total amount and dynamic change of China's industrial carbon emission transfers, explored the economic effect of industrial carbon emission transfers, and proposed strategies for optimizing carbon emission transfer structures. Three main conclusions and policy implications emerge from this work.

(1) Carbon emission imports and exports already occur between different Chinese industries, with positive average annual growth rates and typical industrial characteristics. Specifically, traditional energy industries mainly have high CEI, while processing and manufacturing industries mainly have high CEE. Most light industries have relatively low levels of both carbon emission imports and exports. Therefore, government should not isolate industries when setting carbon emission reduction targets, and should consider carbon emission transfers (import and export) and their effects. Different characteristics of inter-industrial carbon emission transfers also need to be considered, with the government implementing targeted and specific policies and measures.

(2) Overall, carbon emission imports or exports can both promote industrial development; however, exports have more significant economic effects than imports. Under the combined action of exports and imports, the economic effects of industrial carbon emission transfers have typical characteristics. Eight industries experience a positive economic effect from net carbon emission transfers; 15 industries experience a negative economic effect from net carbon emission transfers; and four industries experience a variable economic effect of net carbon emission transfers in different years. Therefore, the government should focus on reducing negative economic effects of inter-industrial carbon emission transfers from 15 industries. In particular, the government should focus on carbon emission exports and reduce the amount of net carbon emission transfer. This can be achieved by increasing productivity and strengthening industrial linkages.

(3) Four strategies are proposed to optimize the industrial carbon emission transfer structure, and achieve the dual objectives of carbon emission reduction and economic development. The economic output of eight of the studied industries can be improved by increasing carbon emission imports and reducing exports. The negative economic effects of six industries can be mitigated by reducing net carbon emission imports and increasing exports. For 11 other industries, increasing carbon emission imports is the first goal. Exports can be subsequently increased to improve economic output. Increasing carbon emission imports for the remaining two industries may help reduce industrial carbon emissions and promote industrial development.

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