The Spillover Effect Evaluation of Chinese Emissions Trading Scheme

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Carbon emissions trading scheme (ETS) is becoming a crucial policy in mitigating global climate change. This paper purposes to evaluate the spillover effect of Chinese ETS policy with the data of 30 provinces' carbon emissions in China by China-MRIO model and input-output analysis. The MRIO model provides the change in production value in each region in the intermediate demand and final demand. 2012 and 2015 were selected as case study years to highlight the spillover effects of ETS policy. The results show that some pilot regions such as Beijing, Tianjin, Shanghai and Chongqing reduced their directed CO_2 emissions while Guangdong and Hubei increased their directed CO_2 compared to 2012. However, there were places like Hebei, Shanxi, Inner Mongolia, Ningxia, and Xinjiang that undertook a mass of embodied CO_2 emissions which were majorly caused by providing intermediate products. Similarly, the pilot regions transferred out CO_2 emissions by using a good deal of intermediate products. Thus, it is argued that carbon transfer evaluation can provide scientific support for carbon allowance formulating and it is important for policymakers to consider embodied carbon emissions in intermediate product trading when allocating carbon allowance under the market strength of ETS.

Keywords: carbon emissions trading scheme, carbon transfer, MRIO model, spillover effect, effect evaluation

INTRODUCTION

China has concerned about further climate change impacts caused by greenhouse gas, and it is undergoing the process of carbon dioxide (CO_2) emission reduction. Since 2006, China has been the first rank of CO_2 emission in the world and added 0.32 billion tones of CO_2 to the atmosphere in 2019. Overall, China emitted 9.83 billion tons of CO_2 emissions, 28.8% of the world's total share in 2019 (BP, 2020). The Paris Agreement was officially in force in 2016. Since then, China was becoming one of the most concerned countries in mitigating climate change. China formally approved Beijing, Shanghai, Tianjin, Chongqing, Hubei, Guangdong, and Shenzhen to practice the "cap and trade" carbon emissions trading scheme (ETS) in 2011. And Shenzhen presented the first practice of ETS in China in 2013. Consequently, environmental and economic impacts of ETS have been a major issue of research over the last decade. The focus of these studies includes carbon price and renewable policies (Koch et al., 2014), firms' inventory management (Hua et al., 2011), carbon allowance allocation (Daskalakis et al., 2009; Zhang et al., 2018) and financial analysis such as carbon trading and tax (Otaki, 2013; Barragán-Beaud et al., 2018). Regression analyses were used to study economics and environmental impacts of the adoption of ETS pilots in China. For example, the authors demonstrated that the trading carbon volume at Shanghai market would

be 6.2 million ton in 2030 (Wu et al., 2016). In other studies, carbon leakage was concerned because products' consuming places were ignored (Peters and Hertwich, 2008a). To overcome this neglect, consumption-based accounting of CO_2 emissions was employed to calculate the exact CO_2 emission (Peters and Hertwich, 2008b; Davis and Caldeira, 2010).

Leontief proposed an IO method to capture the relations between sectors and industries in the 1930s (Leontief, 1970). Further, the single region national input-output (SRIO) model was employed to assess the net transfer of CO_2 between countries which reveals unfair responsibility on emission and negative impacts on developing countries due to providing the majority of industrial products of the world (Su and Ang, 2013; Kulionis and Wood, 2020). However, studies that focus on policy effect or employ the SRIO model cannot evaluate the spatial distribution of impacts. One limitation of the studies based on SRIO and regression is that they treat the entire state economy as one and incapable of calculating region-wise impacts. On the other hand, the MRIO model can identify trading flows between regions, sectors, and final demand. Therefore, the MRIO model can effectively distinguish the pollutant emissions in other regions caused by the consumption of a given region (Wiedmann et al., 2011).

Implementing carbon ETS pilots could result in regional spillover of environmental and economic impacts due to the interconnected nature of the regional production structure. Hence, it is crucial to quantify the distribution of these impacts to avoid any unplanned consequence of ETS pilots' expansion. To our best knowledge, few studies quantified the regional spillover effects for ETS pilots implementation in China, which can provide important multi-regional insights for policy management departments to allocate carbon allowance between provinces reasonably. Thus, the multi-regional input-output (MRIO) model is employed in this paper to address the gap of multi-regional impacts of carbon transfer during the ETS pilots period.

The MRIO model enables us to compute the spillover effects of ETS pilots among the six pilot provinces and all the other interconnected regions. These spillover effects can be in the form of change in energy consumption and production volume of different commodities in regions that are not included in ETS pilots. This advantage of MRIO methodology to provide a comprehensive insight into spillover effects across different areas because of planned changes in the economic sectors of a region makes MRIO a robust tool to be used for assessing the impact of planned development. Thanks to the fast evolution of technology, MRIO data panels are available for assessment of the impact of these emerging pilot policies before wide-scale adoption (Liang et al., 2007; Mi et al., 2018). Nowadays, there are several studies that work out net transferred CO_2 based on China's MRIO data table (Meng et al., 2013; Mi et al., 2017). Nevertheless, the multi-regional CO_2 flow behind the ETS pilots is not fully understood.

In this paper, we perform calculation analysis and attempt to answer the following two questions: (1) How much would the carbon emissions change pre- and post-the ETS pilots' intervention? (2) What can we know about the spillover effects

that an MRIO can provide for the case of implementing ETS pilots in China? To address these issues, we first compute every province's CO_2 emission considering both the production side and consumption side by using China's MRIO model and then indicate the direction of CO_2 transfer among provinces. The China-MRIO table can capture regional contribution and distribution of CO_2 emission.

In sum, this study considers the potential changes of carbon emissions transfer to help understand the effect of ETS policy implementation within China. By breaking up the CO_2 emissions into the intermediate trade and final consumption, we can figure out the adjustment of CO_2 transfer of the pilot regions and the transfer directions of CO_2 emissions. The results of this study could facilitate the optimization of China's ETS pilots policy and minimize the adverse side effects of the policy implementation on the economy and environment.

The Rest of this paper is organized as follows: we first provide the details about calculating regional level direct and indirect CO_2 emission with MRIO analytical framework and the China-MRIO data table. This is followed by details on data sources used for studying energy consumption and carbon footprint between pilots and non-pilots areas of China. In the "Results and Discussions" section, we report our major findings for decomposition of regional level CO_2 emissions, embodied CO_2 emissions for regional sector using MRIO model and CO_2 transfer impact of executing ETS pilots followed by conclusion from the work.

METHODOLOGY AND DATA SOURCES

Calculation of Carbon Emission and Carbon Intensity

In this study, the equation that we use to estimate carbon emissions is defined below (Liu et al., 2016) :

$$CE = \sum D \times e \qquad (1)$$

Where CE is CO_2 emissions from different sectors of regions, D is the combusted fossil fuels measuring in monetary; and e is the CO_2 emission of different types of energy per monetary unit.

By summarizing the emissions from different fossil fuels together, we calculate the emission intensity for a region in the following equation:

$$CI^r = CE/GDP^r \qquad (2)$$

where CI^r is the CO_2 emission intensity for a region, and GDP^r is the gross domestic product of that region.

MRIO Model

This paper employs the MRIO model to estimate the spillover effect of carbon transfer under the ETS policy in China. The MRIO model internalizes the stream of commodities and services among areas using inter-regional trading data which present as an MRIO table. The methodology starts with an existing m region MRIO table (Aichele and Felbermayr, 2015). The

"Intermediate product" provides the input-output data from a region's department itself and other regions' departments; the "Final Product" provides the final consumption data of a region from every region's departments.

Since the MRIO matrix has been established, area r's input-output identical equation can be defined as follows:

$$Q = (I - A)^{-1} (AX + Y + EX) \quad (3)$$

Where Q is the total output of the system; A is the direct consume coefficient matrix whose elements indicate the number of intermediate products from sector i in region r that produces a unit output for sector j in region s; X is a vector representing the intermediate demand; and Y is a vector representing the final demand, including household consumption, government consumption, fixed asset formation and inventory; EX is a vector indicating the net export.

To calculate the spatial CO_2 footprint of economic activities across China, we first construct a carbon intensity matrix which is symbolized by CI^r to indicate the CO_2 emissions per unit output of region r. If the X, Y, and EX in Eq. 3 are known, then the carbon emissions of departments of region r can be calculated as follows:

$$E^r = CI^r (I - A)^{-1} (AX + Y + EX) \quad (4)$$

Where CI^r is a vector whose elements are identified as the amount of direct CO_2 emissions per unit GDP; $(I - A)^{-1}$ is the Leontief inverse matrix.

The net CO_2 emission transfer can be calculated as follows:

$$netET^r = E^r_{pro} - E^r_{con} \quad (5)$$

Where $netET^r$ is the net CO_2 transfer from region r to other regions. If the $netET^r > 0$, region r is the embodied CO_2 importer; respectively, if the $netET^r < 0$, region r is the embodied CO_2 exporter.

By breaking it down into different demands, the net CO_2 emission transfer of the intermediate demand can be calculated as follows:

$$netET^r_{in} = CI^r (I - A)^{-1} A (X_{pro} - X_{con}) \quad (6)$$

Where $netET^r_{in}$ is the net CO_2 transfer resulted from the consume and produce of intermediate products; X_{pro} is the vector indicates the intermediate products produced in region r and consumed in other regions; and X_{con} is the vector indicates the intermediate products produced in other regions and consumed in region r.

The net CO_2 emission transfer of the final demand can be calculated as follows:

$$netET^r_{fi} = CI^r (I - A)^{-1} (Y_{pro} - X_{con}) \quad (7)$$

Where $netET^r_{fi}$ is the net CO_2 transfer resulted from the consume and produce of final products; Y_{pro} is the vector indicates the final products produced in region r and consumed in other regions; and Y_{con} is the vector indicates the final products produced in other regions and consumed in region r.

The domestic net CO_2 emission transfer can be calculated as follows:

$$netET^r_d = netET^r_{in} + netET^r_{fi} \quad (8)$$

Where is $netET^r_d$ the net CO_2 transfer between region r and other regions in China. If the $netET^r_d > 0$, region r imports the embodied CO_2 from other regions in China; respectively, if the $netET^r_d < 0$, region r exports the embodied CO_2 to other regions in China.

Since this study focus on the spillover effect of ETS policy implementation within China, we need to pay attention to the results of Eqs 6–8.

Data Sources

Two types of data are needed in this research, including China's national MRIO table and annual emission inventories of 30 provinces in China. This research is conducted to analyze the spillover effect of ETS pilots implementation which was carried out in 2013 and 2014. By the way, the shift of labor-intensive and resource-intensive industries in eastern China to the central and western regions is accelerating in 2010, thus selecting 2012 and 2015 as the case study years is helpful to detect the ETS policy's effects and defects. The data of 2012 MRIO table and 2015 MRIO table are the most recent data that are available from the China Emission Accounting and Datasets (CEADs) (CEADs, 2012, 2015; Liu et al., 2016). The datasets published by CEADs are the results of current research projects funded by the National Natural Science Foundation of China, Ministry of Science and Technology of China, Chinese Academy of Sciences, Science and Technology Research Council UK, Newton Fund, which ensure the accuracy of economic and trade data in the MRIO table. The industries in the 2015 MRIO table were merged into 30 industries to reconcile 2012 and 2015's different classification criteria. The MRIO table consists of 30 provinces and 30 industrial departments, and the missing data of Tibet, Hongkong, Macao, and Taiwan are unavailable so that this research does not include these regions. Data of energy activities for calculating CO_2 emissions was capturing via the National energy balance sheet in *China Energy Statistical Yearbook 2013 And China Energy Statistical Yearbook 2016* which recorded previous year data. Besides, carbon emission factors that we use are recommended in the IPCC 2006 guidelines (IPCC, 2014). Due to the China-MRIO table contains four energy industries which are Coal mining, Petroleum and gas, Petroleum refining and coking and Gas and water production and supply, we categorize energy materials that every province consumes into these four energy genres (Wang et al., 2017). Besides, the part of energy materials to convert has to be distinguished which will result in overrating emissions of intermediate consumption and underrating emissions of final consumption (Liu Y. et al., 2015).

RESULTS

Provincial Level Direct CO_2 Emission and Emission Intensity
Direct CO_2 Emission
Based on the methodology and relevant data files above, China emitted 8,623 million tons (million tons) CO_2 in 2012 and 9,231 million tons CO_2 in 2015, which are basically matching with the results of existing researches (Liu Z. et al., 2015; Shan et al., 2018).

Figure 1 provides an overview of variations of CO_2 emissions of 2012 and 2015. In 2012, top five emitting provinces were Shandong, Hebei, Jiangsu, Hebei, Henan, and Guangdong and they shared 41.48% of total emissions. The biggest emitter was Shandong which produced 1,002.54 million tons CO_2. In 2015, Jiangsu, Guangdong, Shandong, Hebei, and Zhejiang became the top five spots direct CO_2 emissions and they shared 42.27% of total emissions. And then the biggest emitter was Jiangsu which emitted 1,049.12 million tons CO_2.

The CO_2 emitted by six pilot provinces increased from 1,322.47 million tons in 2012 to 1,638.43 million tons in 2015, the differential of which was generated by Guangdong and Hubei. During this period, Beijing, Tianjin, Shanghai and Chongqing decreased their share of direct CO_2 emissions while Guangdong raised its share of direct CO_2 emissions from 5.80 to 8.52% and Hubei's share rised from 2.22 to 4.10%.

CO_2 Emission Intensity

According to **Figure 2**, the carbon emission intensity top five were Qinghai, Ningxia, Gansu, Hebei, and Guizhou in 2012, while in 2015 were Ningxia, Xinjiang, Guizhou, Anhui, and Gansu. And the quantity of emission intensity of these regions were in a strong uptrend. It is shown that the emission intensities of the six pilot places remained low. Besides, Beijing, Tianjin, Shanghai, and Chongqing had slightly declined. Correspondingly, Guangdong increased its emission intensity from 0.87 tons per 10 k RMB in 2012 to 1.38 tons per 10 k RMB in 2015 and Hubei's emission intensity increased from 0.86 tons per 10 k RMB in 2012 to 1.70 tons per 10 k RMB in 2015.

Carbon Footprint

Implementing ETS pilots induces new regional throughput for the whole of China. Using Eqs 8, 9, we calculate 30 provinces' carbon footprint of production and carbon footprint of consumption in 2 years, respectively, and the results are presented in **Table 1**.

Carbon Footprint of Consumption

Beijing, Tianjin, Shanghai, Hubei, Guangdong, and Chongqing increased much more CO_2 emissions by 146.08 million tons, 30.04 million tons, 229.79 million tons, 234.02 million tons, 780.92 million tons and 190.79 million tons, respectively, through consuming intermediate and final products from other provinces from 2012 to 2015. In 2012, the pilot regions contributed 24.2% of consumption-based CO_2 emissions. And in 2015, the pilot regions shared 27.6% of the carbon footprint of consumption.

Carbon Footprint of Production

From 2012 to 2015, the majority of provinces were increasing their CO_2 emissions due to production activities within the province boundary. Only Beijing, Tianjin, Shanghai, Sichuan, and Yunnan's carbon footprint of production were declining. Beijing's carbon emission of production dropped from 147.43 million tons in 2012 to 75.00 million tons in 2015. Tianjin reduced about 96.36 million tons of carbon emissions in production activity. And Shanghai decreased slightly by 9.17 million tons.

Carbon Transfer of Provinces

According to **Figure 3**, Beijing's domestic CO_2 emissions transfer in 2015 was −395.74 million tons which were more than twofold that in 2012. Tianjin's net CO_2 emissions transfer was −109.30 million tons which was reversed a lot in volume from 2012. Shanghai's net CO_2 emissions transfer was −238.46 million tons which was about fourfold that in 2012. Guangdong's net CO_2 emissions transfer was −575.63 million tons which is much higher than that in 2012. This situation also emerged in Chongqing.
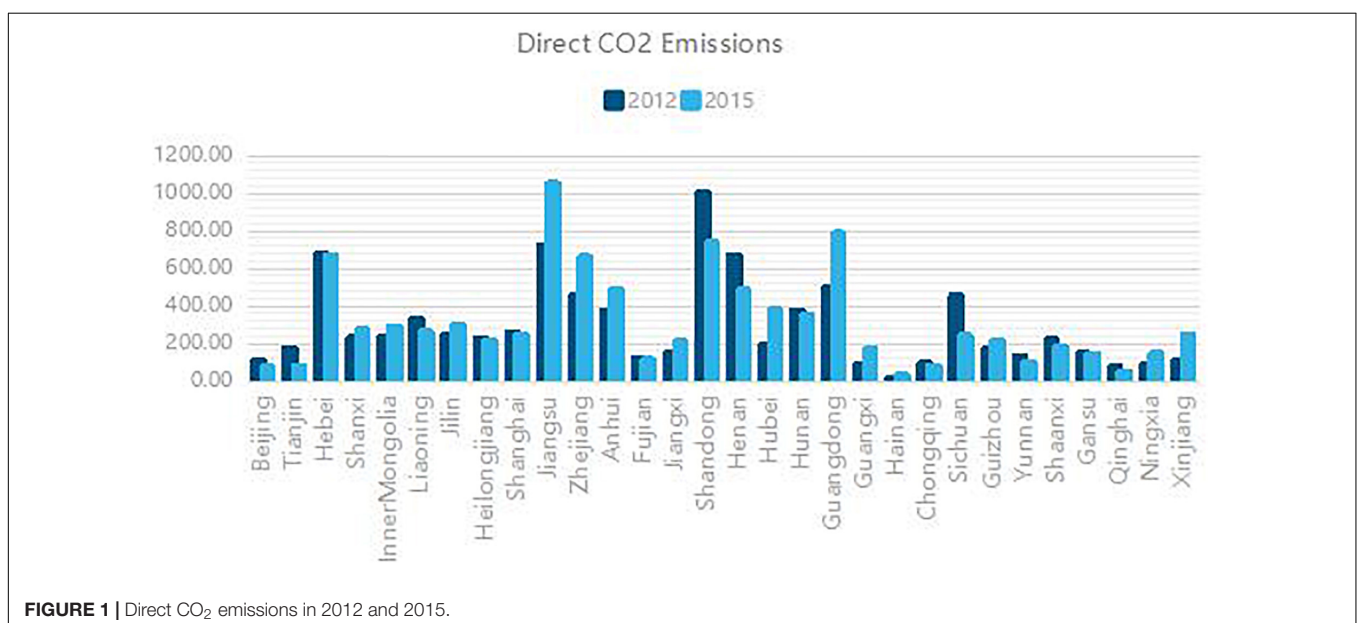

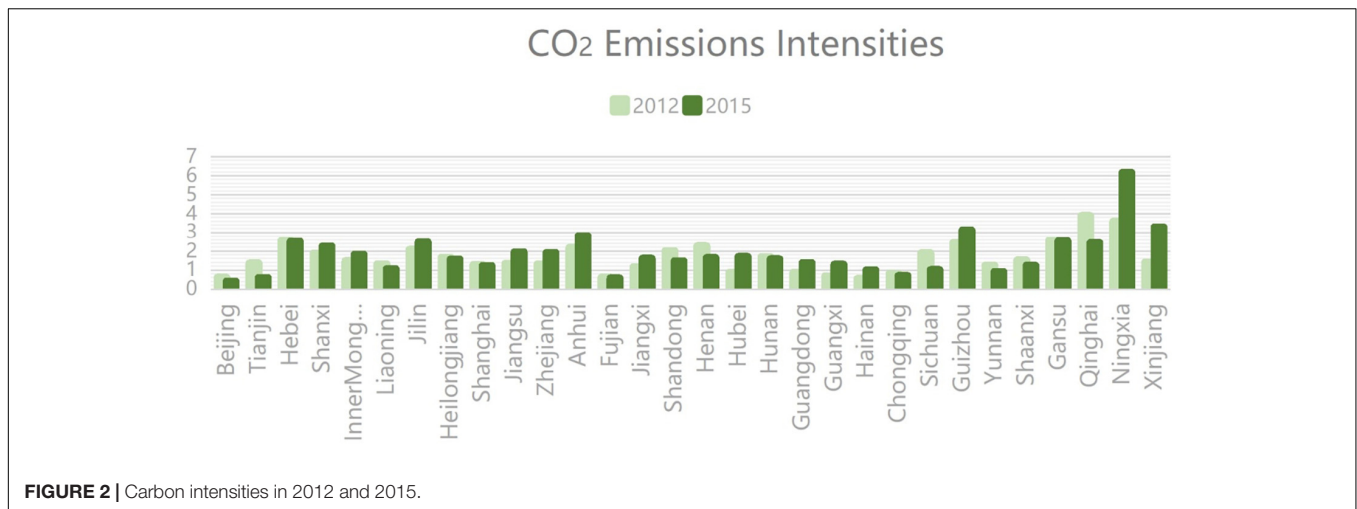**FIGURE 1 |** Direct CO_2 emissions in 2012 and 2015.

FIGURE 2 | Carbon intensities in 2012 and 2015.

TABLE 1 | CO_2 emissions and transfer calculation of 30 province in China in 2012 and 2015 (Unit: Mt).

Region	2012			2015		
	Intermediate products	Final product	Domestic	Intermediate products	Final product	Domestic
Beijing	−139.68	−25.62	−165.3	−368.16	−27.58	−395.74
Tianjin	21.55	−5.01	16.54	−97.44	−11.86	−109.3
Hebei	184.87	30.69	215.56	615.46	29.99	645.45
Shanxi	50.06	−14.95	35.11	330.62	−14.24	316.38
InnerMongolia	68.28	−1.65	66.63	455.08	2.17	457.25
Liaoning	−17.54	78.11	60.57	−31.06	88.95	57.89
Jilin	34.52	8.12	42.64	93.37	12.12	105.49
Heilongjiang	43.98	−8.14	35.84	60.54	−11.13	49.41
Shanghai	−26.95	−18.98	−45.93	−213.39	−25.07	−238.46
Jiangsu	−144.47	13.95	−130.52	−190.81	29.57	−161.24
Zhejiang	−96.53	−2.76	−99.29	−571.96	6.73	−565.23
Anhui	42.70	14.90	57.6	198.36	26.45	224.81
Fujian	−11.12	3.20	−7.92	−77.15	2.62	−74.53
Jiangxi	−19.63	−4.31	−23.94	−30.11	−2.41	−32.52
Shandong	−1.10	9.73	8.63	27.52	1.07	28.59
Henan	91.90	27.76	119.66	−39.51	8.03	−31.48
Hubei	−19.66	0.97	−18.69	−119.14	5.75	−113.39
Hunan	21.57	19.22	40.79	−63.44	15.95	−47.49
Guangdong	−95.00	−10.78	−105.78	−569.48	−6.15	−575.63
Guangxi	−16.36	−8.81	−25.17	10.90	−5.01	5.89
Hainan	−9.30	−3.44	−12.74	−34.56	−2.99	−37.55
Chongqing	−56.31	−14.95	−71.26	−234.09	−16.05	−250.14
Sichuan	−1.02	9.25	8.23	−103.39	0.76	−102.63
Guizhou	32.84	3.35	36.19	182.73	7.18	189.91
Yunnan	−12.07	−5.81	−17.88	−109.81	−10.98	−120.79
Shaanxi	15.81	−12.74	3.07	−17.82	−14.61	−32.43
Gansu	25.66	−0.30	25.36	107.93	−0.79	107.14
Qinghai	7.87	−2.62	5.25	34.04	−2.88	31.16
Ningxia	24.63	0.17	24.8	370.53	2.21	372.74
Xinjiang	0.49	−9.12	−8.63	384.21	−0.75	383.46

The negative numbers indicate that regions export embodied carbon emissions; The positive numbers indicate that regions import embodied carbon emissions.

In addition, we can figure out that Hebei, Inner Mongolia, Xinjiang, Ningxia, Shanxi, and Anhui digested the vast majority of CO_2 emissions transfer. Their CO_2 emissions imports dramatically increased by hundreds of million tons. Their transferred-in quantities increased 429.89 million tons, 390.62 million tons, 392.09 million tons, 347.94 million tons,
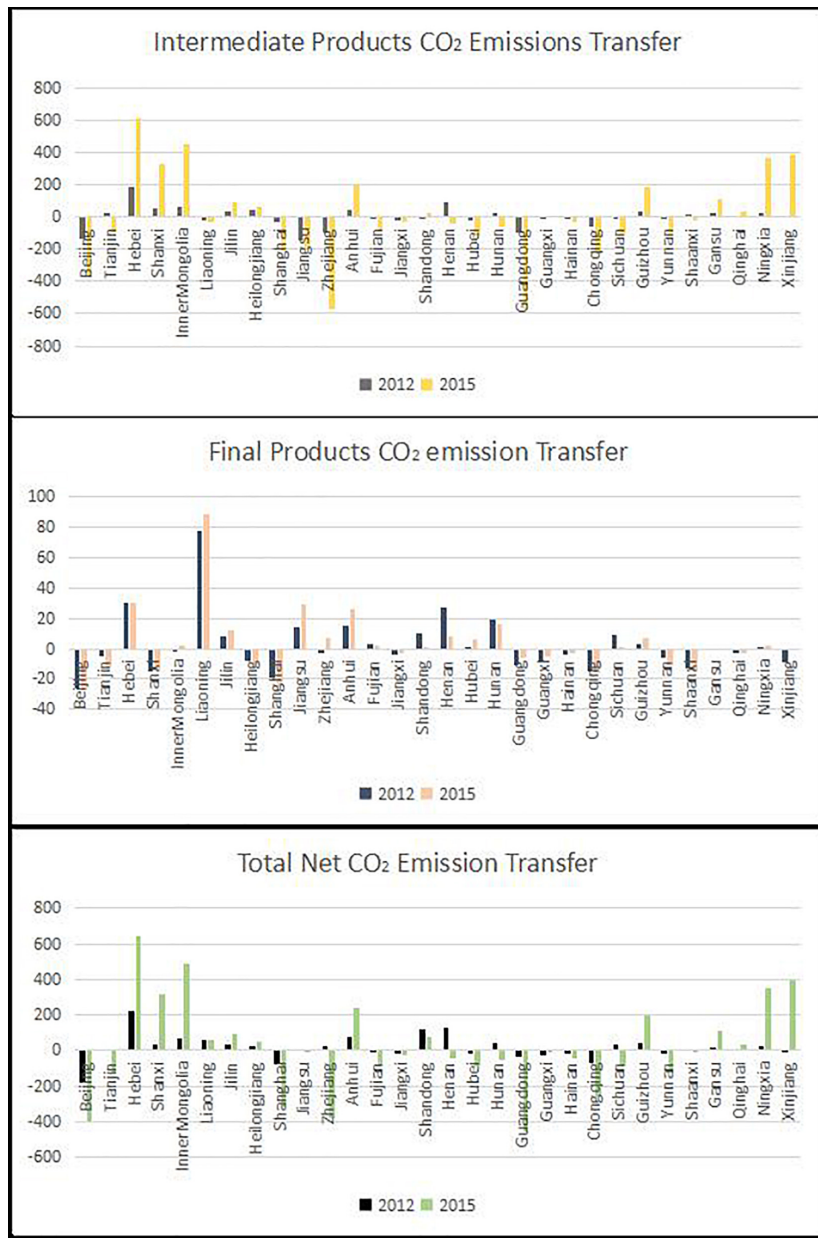
FIGURE 3 | Details of CO_2 transfer in 2012 and 2015.

281.27 million tons, and 167.21 million tons, respectively, in 2015.

In terms of the CO_2 emissions transfer of two types of products, Beijing, Tianjin, Shanghai, Hubei, Fujian, Guangdong, and Chongqing increased much more CO_2 emissions exports by 228.49 million tons, 118.99 million tons, 186.43 million tons, 99.48 million tons, 66.03 million tons, 474.47 million tons, and 177.77, respectively, by consuming intermediate products from other provinces in 2015. Hebei, Shanxi, Inner Mongolia, Anhui, Ningxia, and Xinjiang augmented a lot of importing CO_2 by 430.59 million tons, 280.56 million tons, 386.80 million tons, 155.65 million tons, 345.90 million tons, and 383.72 million tons

due to providing much more intermediate products relatively in 2015. In addition, Jiangsu, Zhejiang, Hunan, and Hubei were the same bearing transferred-in CO_2 emissions due to providing final products although they transfer CO_2 emissions out by purchasing intermediate products.

Carbon Transfer Between Provinces

The details of multi-regional CO_2 emissions transfer in 2015 for analyzing transferring properties between provinces are calculated and shown in **Table 2**. It must be noticed that the row data express the transferring volume of CO_2 by consuming intermediate and final products provided by other provinces. For

TABLE 2 | Details of multi-regional CO_2 emissions transfer for consuming intermediate and final products.

	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning	Jilin	Heilongjiang	Shanghai	Jiangsu	Zhejiang	Anhui	Fujian	Jiangxi	Shandong
Beijing		4.67	59.82	19.61	34.99	11.32	11.19	9.06	8.00	46.98	11.06	41.88	2.34	6.47	23.64
Tianjin	1.61		20.92	5.74	9.00	4.98	7.11	6.35	2.50	17.21	4.48	16.82	0.65	2.09	7.13
Hebei	1.91	2.00		26.33	23.82	6.62	6.42	7.44	6.74	18.97	4.47	17.59	0.67	3.45	11.55
Shanxi	0.46	1.21	19.27		9.08	2.56	7.29	2.63	2.94	16.90	2.69	17.92	0.70	1.81	8.76
Inner Mongolia	0.72	1.16	15.51	5.72		5.12	4.52	5.16	2.64	16.33	4.71	14.98	1.21	1.60	8.89
Liaoning	0.64	1.64	22.80	8.74	15.32		14.51	8.09	4.52	25.29	5.69	24.92	1.29	2.86	10.22
Jilin	1.02	1.18	11.27	12.98	10.23	5.46		2.58	3.89	9.49	4.86	9.79	1.12	1.25	6.47
Heilongjiang	0.53	0.87	14.69	6.90	10.04	5.85	16.48		2.53	11.37	4.21	13.30	0.76	2.36	7.17
Shanghai	1.06	2.79	36.06	22.56	26.97	11.32	12.11	11.74		43.59	19.15	50.64	2.97	6.02	21.28
Jiangsu	1.30	4.90	103.42	63.35	84.01	14.11	19.76	16.20	12.47		16.58	106.91	2.59	18.27	33.67
Zhejiang	1.74	4.00	89.46	40.86	60.27	18.77	19.19	14.78	19.49	68.38		90.44	3.37	21.56	31.13
Anhui	2.23	3.72	82.60	39.00	47.81	19.74	8.68	16.36	20.51	54.63	21.59		3.08	15.21	36.20
Fujian	0.15	0.70	10.69	4.21	7.41	1.90	5.71	2.93	2.82	12.96	3.06	15.58		2.24	4.64
Jiangxi	0.84	0.94	15.91	17.02	16.41	2.59	4.54	5.14	3.69	12.74	5.43	21.27	1.24		4.23
Shandong	1.34	2.07	43.16	27.06	33.89	7.69	8.82	23.69	6.23	10.19	4.34	22.00	0.98	3.39	
Henan	1.91	3.16	74.57	19.46	36.96	15.56	12.42	14.01	15.47	44.14	19.44	58.30	1.60	8.96	38.17
Hubei	1.02	1.40	13.98	26.25	22.99	2.90	4.93	6.42	2.70	7.22	5.55	17.33	1.32	2.02	5.08
Hunan	0.41	1.01	20.29	17.09	17.63	4.36	4.25	3.51	3.71	12.16	5.60	18.90	1.15	3.67	10.46
Guangdong	2.58	5.20	74.47	44.37	43.89	13.22	18.49	14.67	17.36	79.36	15.26	86.07	4.36	12.21	31.86
Guangxi	0.50	0.79	9.27	7.78	6.65	2.65	3.57	2.16	4.59	13.38	4.94	13.40	0.95	1.58	5.71
Hainan	0.09	0.42	5.47	2.05	4.17	0.92	1.68	1.76	1.16	5.92	1.58	7.40	0.44	1.05	2.19
Chongqing	0.87	1.60	33.36	10.07	20.80	5.99	5.59	5.09	5.31	21.19	7.08	29.20	1.84	5.66	11.87
Sichuan	0.35	1.02	17.01	5.27	11.61	2.69	3.98	2.91	3.34	18.17	2.89	19.35	0.87	2.98	5.47
Guizhou	0.39	0.81	12.04	3.25	6.10	2.64	2.45	2.01	3.38	11.81	3.60	12.50	0.88	1.82	6.57
Yunnan	0.38	0.84	13.57	3.33	5.33	2.76	3.90	2.27	3.51	24.20	6.74	21.64	1.80	2.78	8.33
Shaanxi	0.86	1.75	22.89	7.69	15.41	3.94	4.95	3.93	5.18	26.35	8.12	27.74	1.87	3.39	10.48
Gansu	0.23	0.75	8.52	3.11	10.28	1.35	3.52	1.51	1.82	10.04	2.55	11.02	0.70	1.30	5.08
Qinghai	0.10	0.14	1.27	2.07	1.46	0.35	0.60	0.48	0.45	1.69	0.79	1.86	0.17	0.20	0.92
Ningxia	0.09	0.23	4.49	3.85	5.65	0.69	1.97	1.48	0.57	2.56	0.76	3.97	0.20	0.47	1.60
Xinjiang	0.42	0.44	9.88	1.49	6.61	1.94	1.93	1.81	2.52	8.43	4.07	7.37	0.50	1.08	5.06

	Henan	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
Beijing	28.39	4.26	6.38	8.55	5.20	1.08	1.85	2.26	10.48	2.57	7.51	9.23	1.84	20.52	20.33
Tianjin	13.61	2.35	3.02	2.43	2.12	0.58	0.88	1.29	5.16	1.04	2.63	3.46	0.53	4.89	10.12
Hebei	13.99	2.78	3.69	2.64	2.43	0.82	1.29	1.57	7.87	1.42	6.32	6.84	1.97	14.53	15.08
Shanxi	12.69	1.99	3.23	2.85	2.20	0.14	1.24	1.07	3.89	0.52	2.81	2.30	0.65	7.09	3.96
Inner Mongolia	8.47	1.38	2.93	3.19	1.88	0.63	0.99	0.98	4.12	0.82	3.57	5.07	0.27	14.28	10.66
Liaoning	13.83	2.27	3.59	4.33	2.82	0.30	1.36	1.39	5.61	0.84	3.97	3.22	0.94	9.18	9.50
Jilin	5.19	0.63	1.41	2.18	0.80	0.30	0.73	0.43	2.45	0.72	2.59	2.52	0.41	8.99	4.15
Heilongjiang	8.70	1.21	3.12	2.36	1.97	0.39	0.68	0.76	5.57	0.77	3.00	3.53	0.66	8.94	8.04
Shanghai	24.36	4.64	7.79	9.11	4.55	1.18	3.09	3.07	11.05	2.33	9.78	8.53	1.59	22.62	26.53
Jiangsu	63.37	8.74	14.81	11.75	15.11	1.50	3.35	4.79	34.03	4.69	24.36	23.24	7.53	54.73	43.36
Zhejiang	65.40	11.26	16.94	11.14	12.94	1.68	3.55	2.65	27.02	4.43	17.66	23.86	8.77	38.74	37.03
Anhui	36.14	7.16	11.36	9.45	9.34	2.87	3.11	2.92	18.70	4.67	16.09	19.45	4.75	26.08	31.84
Fujian	7.53	1.41	3.19	2.16	2.11	0.19	1.03	1.17	5.37	0.89	1.97	2.44	0.71	5.22	5.77
Jiangxi	7.84	1.31	2.73	2.96	2.30	0.59	1.02	1.20	7.90	1.28	4.33	2.89	0.43	8.95	12.55

(Continued)

TABLE 2 | Continued

	Henan	Hubei	Hunan	Guangdong	Guangxi	Hainan	Chongqing	Sichuan	Guizhou	Yunnan	Shaanxi	Gansu	Qinghai	Ningxia	Xinjiang
Shandong	9.06	0.48	4.80	3.20	5.92	2.69	2.28	1.30	14.01	2.29	14.30	11.47	1.79	9.18	57.62
Henan		4.67	12.16	9.34	8.35	2.49	3.34	3.30	15.29	3.40	16.60	16.07	2.43	25.65	24.35
Hubei	8.31		2.63	3.39	2.61	0.59	1.18	1.44	10.82	1.72	6.37	4.90	0.85	15.80	17.70
Hunan	13.01	2.42		5.21	3.60	0.85	1.24	1.78	10.96	1.19	6.52	5.56	1.15	16.78	8.67
Guangdong	38.89	9.97	17.32		17.16	3.22	6.02	4.93	38.33	4.27	17.32	16.98	3.58	38.54	32.11
Guangxi	5.88	1.43	3.13	5.03		0.75	1.89	1.21	7.67	0.92	2.82	2.17	0.42	6.67	4.51
Hainan	4.28	0.76	2.00	2.49	2.30		0.49	0.52	3.67	0.56	1.63	1.34	0.45	2.17	5.02
Chongqing	23.07	3.49	7.70	6.95	6.37	0.85		3.99	17.39	3.34	7.00	11.65	3.31	19.44	19.48
Sichuan	10.16	1.56	4.13	3.52	3.15	0.40	1.61		6.88	1.25	3.37	4.68	1.40	8.05	8.09
Guizhou	6.97	1.54	2.96	3.90	2.72	0.57	1.38	1.31		1.08	2.48	3.05	0.67	6.21	4.51
Yunnan	13.24	2.78	4.54	6.85	3.84	0.69	1.75	2.28	10.25		3.41	3.54	0.81	9.26	6.36
Shaanxi	18.01	2.87	5.35	5.43	3.13	0.49	2.18	2.35	7.43	1.89		5.44	1.28	10.75	16.20
Gansu	7.97	1.11	2.08	2.54	1.40	0.21	0.81	1.45	3.26	0.56	2.43		1.82	5.07	8.00
Qinghai	0.93	0.18	0.32	0.71	0.35	0.08	0.20	0.44	0.91	0.16	0.52	0.92		2.12	1.30
Ningxia	3.94	0.46	0.70	0.63	0.62	0.07	0.24	0.39	1.54	0.14	1.95	0.97	0.66		9.93
Xinjiang	6.86	0.92	1.65	2.08	1.02	0.27	0.66	1.27	1.90	0.46	2.10	2.29	1.18	3.10	

The numbers in this table indicate the net CO_2 exportation among provinces. Moreover, the numbers indicate the CO_2 transfer from the region in the first row to the region in the first column. The elements in the diagonal are empty for this table focusing on the regional carbon transfer.

example, the data located at the second line and third column indicated that Beijing transfers CO_2 to Tianjin by using Tianjin's intermediate and final products.

As mentioned previously, the quantity of CO_2 transfer of the six pilot places had increased a lot in 2015 compared to the volume in 2012. Guangdong was the biggest CO_2 exporter in 2015, and it mainly transferred to Jiangsu (79.36 million tons), Anhui (86.07 million tons), Hebei (74.47 million tons), Henan (38.89 million tons), and Ningxia (38.54 million tons) which indicated that Guangdong used these regions' products as primary sources. Followed Guangdong, Beijing was the second CO_2 exporter who mainly transferred to Inner Mongolia (34.99 million tons), Hebei (59.82 million tons), Jiangsu (46.98 million tons), and Anhui (41.88 million tons). Overview, we can figure out that embodied CO_2 emissions continued to flow to nearby provinces and Northern, central and northwest provinces of China which were also poorly-developed in economics according to **Table 2**. Interestingly, Jiangsu, a developed province whose GDP ranked second place after Guangdong in 2015, accepted embodied CO_2 emissions from pilot regions as a primary recipient. It is believed that Jiangsu created increment mainly through manufacturing.

DISCUSSION

The present study was designed to determine the effect of ETS implementation on multi-regional carbon footprint in China. The MRIO analysis results showed that the six early pilot provinces enhanced their CO_2 emissions exports from 372.48 million tons in 2012 to 1631.63 million tons in 2015 after ETS policy implementation.

From the standpoint of direct carbon emissions, the reduction potential of pilot regions was limited. However, the results showed that the carbon emission intensity of pilot regions remained low even a bit lower, which may be explained by the development of tertiary industry and allow them to create more value with less energy consumption. This encouraging result indicates that both to develop and to reduce emission and it had better further consider improving the combustion efficiency.

In terms of emission responsibility, the summarizing carbon footprint of the production of six pilot regions declined by 4.15% from 2012 to 2015, while the six pilot regions' summarizing carbon footprint of consumption increased about 3.39% from 2012 to 2015. From a life cycle perspective, the upstream material consumption in these pilot regions was becoming higher than other regions from 2012 to 2015, for this kind of material required more fossil fuel. Despite the demand within the province boundary, some regions can only develop through undertake high energy consumption industries. For example, Ningxia, Xinjiang, Guizhou, Anhui, and Gansu had much higher carbon intensity in 2015 which indicated that they were producing on low combustion efficiency. These regions were underdeveloped but full of natural resources and inevitably resulted in more carbon emissions in development.

Although some pilot regions decreased their direct carbon emission and carbon emission intensity, the carbon leakage

should take into consideration in defining CO_2 emissions responsibilities, especially the influences on central and western regions of China. According to the calculation above, the pilot regions created much more carbon emission exports comparing to the number of carbon exports in 2012. Conversely, during that period, some provinces endured heavy CO_2 emissions imports. In response to environmental regulations, the pilot regions tended to eliminate backward production and purchased high energy consumption products depending on imports from other regions, which could lead to carbon leakage.

The immense quantity of carbon leakage in China makes it necessary to balance the economy and environment between regions. Thus, laws and regulations should be further improved to regularize actual carbon emissions. Moreover, introducing innovation factors into the western regions with the aid of "China's Western Development Strategy" could improving these backward regions' green economic efficiency encouragingly (Yang et al., 2018).

CONCLUSION

Growing concerns about the impact of greenhouse gas emissions due to rising population and energy demand are leading to the adoption of comprehensive package policies. The CO_2 ETS can play a significant role in reducing CO_2 emissions and the policy's spillover effect should be concerned as well. Therefore, a China-MRIO model was conducted to estimate the spillover effect of ETS implementation in China from 2012 to 2015. In this study, we could demonstrate that the adoption of ETS in six pilot provinces has had a huge positive environmental impact on themselves but negative impacts on the rest of China.

In this paper, the CO_2 emissions on production based and consumption based of 30 provinces were calculated, respectively, by using 2012 MRIO table and 2015 MRIO table. And then the CO_2 transfer among provinces in 2012 and 2015 was computed to capture the spillover effect. The direct CO_2 emissions of pilot regions like Beijing, Tianjin, Shanghai, and Chongqing were reduced, while Guangdong and Hubei which were members of pilot regions increased their direct carbon emissions. Hebei, Shanxi, Inner Mongolia, Ningxia, and Xinjiang increased a mass of transferred-in CO_2 emissions mainly by providing intermediate products, which indicated that ETS pilot regions had transferred a great amount of embodied CO_2 emissions to underdeveloped areas by cutting down intermediate products production and enhancing intermediate products trading. These phenomena also happened in final products trading.

The high emission intensities of central and western China's regions are the first reason for their high carbon emissions for input-output processes. The development of the east and the west is still unbalanced. There should be great variation in resources endowment, economic size, environmental capacity and industrial structure. The low carbon reduction policy is needed to be developed according to the local conditions. The eastern regions of China possess advanced technologies, human talents and intellectual resources, which must place priority on strategic high-tech industries. The rest regions of China need to take due development of forward-looking strategic industries with technology and assistance from the eastern regions of China under Environmental strict constraints.

Moreover, it is necessary to consider building a sound carbon emission credits allocation system based on multi-regional net CO_2 transfer. The embodied carbon transfer among regions results from regional division. With the deepening of regional division, cooperation and commerce, the consumption side should share responsibility with the production side with the support of clearing up carbon transfer direction.

According to the results shown above, China's ETS policy is facing challenges to CO_2 emissions management in multi-regions. The ETS policy is considered as an effective tool to reach the 2030 carbon-neutral vision under the strength of market regulation. However, the 30 provinces of China offer a wide variety of economics and development stages. To guarantee economic growth, underdeveloped areas are likely to undertake more industrial manufacture with much more carbon emissions. Therefore, when allocating carbon allowance, policymakers should not only consider the direct carbon emissions but also be aware of embodied CO_2 emissions that happened in product trading, especially intermediate product trading. Thus, it is helpful to reduce employing intermediate products that require high consumption of energy of downstream companies and promoting efficiency in the production process.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: CEADs, https://www.ceads.net.cn/.

AUTHOR CONTRIBUTIONS

XL, CW, LL, HW conception and design of study, analysis and/or interpretation of data, drafting the manuscript, and approval of the version of the manuscript to be published. XL and LL acquisition of data. XL and CW revising the manuscript critically for important intellectual content. All authors contributed to the article and approved the submitted version.

FUNDING

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