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Carbon emissions embodied in value added chains in China

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ABSTRACT

The literature on carbon leakage and embodied carbon in regional trade is extensive. However, many studies are primarily concerned with emissions embodied in demand-supply chains and ignore the issue of carbon transfer behind the value-added chains. We promote a model to calculate value-based emissions (VBEs) and carbon emissions embodied in the value-added chain using the multi-regional input–output model (MRIO). Taking China as an example, VBEs and carbon emissions embodied in value-added chains at the sub-national level based on MRIO tables for 1997 and 2007 in China were analyzed. Transferred carbon emissions embodied in regional value-added chains in China showed rapid growth between 1997 and 2007. However, the absolute values of inter-regional net transferred carbon emissions embodied in value added chains were small and showed a declining trend. Therefore, the regional inequality between economic growth and carbon emissions pollution reduced between 1997 and 2007, although the amount of emissions embodied in regional value-added chains increased as of the inter-regional economic link in China gained close proximity.

1. Introduction

The global greenhouse effect may be one of the greatest challenges ever to face humankind. Hence, carbon dioxide emission reduction has been the focus of international negotiations, but the results are almost disappointing because along with the reduction of emissions is the loss of economic benefit under the system of pure production-based accounting (PBA) of emissions. In the perspective of PBA, the emissions associated with exports are included but those associated with imports are excluded from the national account. Under this circumstance, many policies designed to reduce CO_2 emissions has been focused on the CO_2 directly emitted by each country, but relatively little attention has been paid to the amount of emissions associated with the consumption of goods and services in each country. Along with the globalization and expansion of international trade, the Annex I countries that have a responsibility to reduce carbon emissions have aimed to do this by relocating their emissions to intensive industries abroad, as well as increasing imports from non-annex I countries without stringent climate change policies. For their part, the non-Annex 1 countries (almost developing and less developed countries) accept this industry transfer from developed countries given the economic benefit it brings them; however, the product technology of most developing countries is generally lower than that of developed countries, meaning that the emission of one unit output is relatively higher, and comes in addition to the emissions caused by forest destruction as the consequence of industrialization in developing countries. Combined, these effects may make global emissions higher. This phenomenon is called “carbon leakage”, one main critique of UNFCCC production-based accounting system (Peters and Hertwich, 2008).

The literature on the carbon leakage problem is extensive (Wyckoff and Roop, 1994; Kondo et al., 1998; Munksgaard and Pedersen, 2001; Ahmad and Wyckoff, 2003; Lenzen et al., 2004; Munksgaard et al., 2005; Wilting and Vringer, 2007; Peters and Hertwich, 2008; Reinaud, 2008; Peters, 2008). These studies are primarily interested in the “weak” definition of carbon leakage (similar to embodied carbon) which considers all trade from non-Annex I to Annex I countries. The IPCC uses a “strong” definition of carbon leakage which only considers carbon outside a region as a direct result of the policy to cap emission in this region (IPCC, 2007). Strong carbon leakage is generally difficult to be distinguished. Additional, many scholars have proposed the consumption-based CO_2 emissions accounting system (Munksgaard et al., 2001; Wilting et al., 2007; Davis and Caldeira, 2010; Barrett et al., 2013; Zsófia, 2013; Yang et al., 2014). Research on “weak” carbon leakage

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or embodied carbon could be roughly divided into two categories. The first category is a separate study on carbon emissions embodied in the trade either internally within a specific country or between two countries (Lenzen, 1998; Sánchez-Chóliz et al., 2004; Pan et al., 2008; Lin and Sun, 2010; Li and Hewitt, 2008; Yu and Wang, 2010; Xu et al., 2009; Dong et al., 2010; Du et al., 2011; Machado et al., 2001; Mäenpää et al., 2007; McGregor et al., 2008; Rhee and Chung, 2006); The second category is a comprehensive study on carbon emissions embodied in global trade between major countries or regions in the world (Ahmad and Wyckoff, 2003; Lenzen et al., 2004; Munksgaard et al., 2005; Davis et al., 2010; Peters et al., 2011; Chen and Chen, 2011; Davis et al., 2011; Bergmann, 2013). Embodied carbon refers to emissions that occur along the supply chain of a functional unit, following the notion of "carbon footprint", "embedded carbon", "virtual carbon", and similar terms. Embodied carbon also has a strong methodological foundation, such as the input–output model and the life-cycle assessment, as well as provides valuable input into policy formation. Life-cycle assessment is generally implemented to calculate carbon embodied in consumer products. The top-down input–output analysis is used by most studies at the national/global level. Authoritative research shows that the carbon emissions embodied in global trade have increased rapidly, with China currently being the world's largest carbon-export country (Peters et al., 2011). By constructing, analyzing, and mapping tens of millions of global connections in empirical portraits of interrelations between regions, economies, and carbon emissions in 2004, Bergmann (2013) indicated that emissions from emerging economies such as China might also be regarded as far more implicated in the supply chains that satisfy the demands of European and American consumers than has been recognized.

In light of these findings, many other scholars began to study the issue of carbon emissions in China (Peters et al., 2007; Guan et al., 2009; Chen and Zhang, 2010). Some scholars have estimated the embodied carbon emissions of China's foreign trade (Pan et al., 2008; Lin et al., 2010; Guo et al., 2012). Their findings show that, in addition to the increase in China's own consumption level and accelerated investment in fixed assets, rapidly expanding export is the other major reason why China has seen an increase in its carbon emissions. Other studies have calculated the embodied carbon emissions in the trade between China and specific countries such as the UK, US, Japan, etc (Li and Hewitt, 2008; Xu et al., 2009; Yu and Wang, 2010; Dong et al., 2010; Du et al., 2011). With the gradual increase in pressure on China to reduce its carbon emissions, the Chinese government has begun to take active measures to implement energy conservation. The government has promised to reduce carbon emissions per unit of GDP by 40%–45% between 2005 and 2020, and has incorporated these carbon reduction targets into the assessment indicators of the provincial administrative regions in economic and social development. However, China is a large country, with great gaps between regions in terms of their resource endowment, economic level, industrial structure and level of carbon emissions (Feng et al., 2009; Afton et al., 2011). Furthermore, it has been argued that the implementation of the regional emission reduction policy may exacerbate the inter-regional carbon leakage problem as there are fewer barriers to trade between the regions than to trade between countries (Feng et al., 2009; Afton et al., 2011; Meng et al., 2011). To engage with this problem, several studies have been conducted that have found a large-scale carbon leakage problem in different Chinese regions (Feng et al., 2013; Guo et al., 2012; Meng et al., 2013; Su and Ang, 2010).

A number of studies have also argued, the assignment of the entire responsibility to the consumer, based on the argument that demand is the only driving force of either production or service provision, is also unrealistic, as accumulation of wealth or increase in the foreign exchange reserves is also an important driving factor to product. The other obstacle to consumption based approach is the lack of direct incentive to improve energy efficiencies in industrial processes especially that for export, in contrast to the producer approach (Bastianoni et al., 2004), as well as its complexity to obtain quality data for use in analysis. An unusual perspective is also taken in Extended Producer Responsibility (EPR) frameworks: 'Producers of products should bear a significant degree of responsibility (physical and/or financial) not only for the environmental impacts of their products downstream from the treatment and disposal of their product, but also for their upstream activities inherent in the selection of materials and in the design of products' (Gallego and Lenzen, 2005). So, some studies promote approach to shared production impacts responsibility between producer and consumer, such as Gallego and Lenzen (2005) presents a formulation for allocating responsibility for production impacts consistently among all agents such as consumers, producers, workers, and investors throughout demand and supply chains, in a way that reflects their contribution to the production process. Lenzen et al. (2007) demonstrates and discusses a non-arbitrary method of consistently delineating demand supply chains, into mutually exclusive and collectively exhaustive portions of responsibility to be shared by all actors in an economy, especially considers attributing emissions to actors in proportion to their share of value added. However, all these studies are primarily concerned with carbon emissions embodied in the demand-supply chains using the technical coefficient matrix of input–output table, while the issue of carbon emissions transfer behind the value-added chain, which could be addressed by the output coefficient matrix in the input–output model, is being ignored. For example, a factory in Region A uses only electricity generated by Region B to produce a particular commodity and obtain added value, and the products of the factory are used by Region B only. According to the principle of consumption-based emissions, no carbon emissions transfer occurs in this case because Region A no identified consumption. However, in the value-added chain perspective, although the economic activity of the factory does not directly produce any carbon emissions, carbon emissions are generated in Region B as a result of the carbon flux between Regions A and B under the value-added chain.

In this paper, the carbon emissions embodied in value-added chains are presented and called as Value-Based Emissions (VBEs). Carbon emissions transfers embodied in value-added chains are also analyzed. This study mainly aims to establish an accounting system for VBEs based on the multi-regional input–output (MRIO) model, and analyze the carbon emissions embodied in value-added chains. China is considered as the subject of the case study. We study Chinese regional VBEs in 1997 and 2007 and compare the changes in carbon emissions embodied in value-added chains to contribute a useful commentary on Chinese regional policies on carbon emissions reduction.

The following section shows how we used the MRIO model to establish the methodology for this study. Subsequently, data sources are discussed and the results are analyzed. This paper ends with the conclusions and policy recommendations.

2. Methods

Multi-region input–output (MRIO) tables and their applications have aroused substantial interest in the forefront of environmental policy debates (Wiedmann, 2009). To perform an MRIO study requires a considerable amount of data, much of which is not directly available. So, various approximations and simplifications should be used in the process of MRIO compilation, such as a common assumption is that imports are produced with domestic production technology. Generally, gravity model would be used to estimate inter-regional commodity flow matrix based on regional Input–Output tables, and then the well-known iterative procedure of bi-proportional adjustment of the RAS technique would be used to find a balanced MRIO table. MRIO tables in China have been estimated in some research projects. For example, State Information Center of China (2005) compiled a MRIO table for the year 1997 in China, which is classified into 8 regions and 30 industries. Ichimura and Wang (2007) estimated a MRIO table with 7 regions and 9 sectors for the year 1987. Liu et al. (2012) and his fellows in the Key Laboratory of Regional Sustainable Development Modeling of China Academy Science finished a MRIO table for the year 2007 in China, which is classified into 30 regions and 30 industries. Liu's work improve traditional gravity model by considering intra-sector impact factors among different regions and adopting Geographical Weighted Regression (GWR) to accommodate the spatial dependences of the dependent variable, for special information, see Liu et al. (2012) or Feng et al. (2013). Table 1 demonstrates the structure of the MRIO model, where a country is demonstrated to have n sub-national regions.

2.1. Direct carbon emissions of industries: production-based emissions (PBEs)

PBE accounting, which is used under the Kyoto Protocol, is a straightforward approach to account carbon emissions. This approach is characterized by clear system boundaries and good data availability. In this study, we represent the PBE of the country as C_{PRO}, and the PBE of Region r as c^r_{pro}. The PBE of Region r, when divided by the total output in Region r, could indicate the quantity of direct carbon emissions per unit of output, namely, the direct carbon emissions factor of Region r, which is demonstrated by the following formula:

$$f^r = c^r_{\mathrm{pro}} \Big/ x^r \tag{1}$$

2.2. Carbon emissions embodied in value added chains: value-based emissions (VBEs)

Given that $h^{rs} = x^{rs}/x^r$, based on the longitudinal direction in Table 1, the following equation could be obtained:

$$\sum_r h^{rs} \bullet x^r + v^s = x^s \tag{2}$$

Written in matrix form, and after transformation, following is obtained:

$$X = \left(I - H^T\right)^{-1} \bullet V \tag{3}$$

where $H = |h^{rs}|$, represents the output coefficient matrix. We denote $(I\text{-}H^T)^{-1}$ by K, the national gross carbon emissions could then be obtained by multiplying by f^r as follows:

$$C_{\mathrm{PRO}} = F \bullet X = F \bullet K \bullet V \tag{4}$$

where F is the row matrix of f^r, specifically:

$$F \bullet X = \left(f^1 \cdots f^r \cdots f^n\right) \bullet \begin{pmatrix} k^{11} & k^{12} & \cdots & k^{1n} \\ k^{21} & k^{22} & \cdots & k^{2n} \\ \vdots & \vdots & \ddots & \vdots \\ k^{n1} & k^{n2} & \cdots & k^{nn} \end{pmatrix} \bullet \begin{bmatrix} v^1 \\ v^2 \\ \vdots \\ v^n \end{bmatrix} \tag{5}$$

where k^{rs} is a block matrix in $(I\text{-}H^T)^{-1}$, which refers to the cumulative output requirements in r to create unit added value in region s. Thus, according to formula (5), the direct emissions in r could be expressed as follows:

$$c^r_{\mathrm{pro}} = f^r \bullet \sum_s k^{rs} \bullet v^s \tag{6}$$

The direct emissions in Region r caused by the added value in s — in other words, the Carbon Embodied in the Added Value Chain (CEAVC for short) from r to s — could be written as:

$$c^{rs}_{\mathrm{val}} = f^r \bullet k^{rs} \bullet v^s \tag{7}$$

Given the arbitrary nature of r and s, according to the principle of symmetry, we could also obtain the direct carbon emissions in Region s, which are caused by the economic growth in Region r, in other words, the flow of carbon emissions embodied in the added value chain from s to r could be represented as:

$$c^{sr}_{\mathrm{val}} = f^s \bullet k^{sr} \bullet v^r \tag{8}$$

Therefore, the total emissions caused by an increase in economic activity (i.e., added value) in s could be obtained using the following equations:

$$c^s_{\mathrm{val}} = \sum_r c^{rs}_{\mathrm{val}} \tag{9}$$

where c^s_{val} solely refers to the VBE of Region s, which reflect the gross emissions impact of economic growth in Region s, if c^s_{val} is used to assess the emissions responsibility of region s, this method would be more straightforward than that in allocating emissions transacted in demand-supply chains to agents in proportion to their share of value added, as suggested by Lenzen et al. (2007). The direct emissions in Region s also could be rewritten as follows:

$$c^s_{\mathrm{pro}} = \sum_r c^{sr}_{val} \tag{10}$$

Finally, the net CEAVC from r to s could be calculated by:

$$nc^{rs}_{\mathrm{val}} = c^{rs}_{\mathrm{val}} - c^{sr}_{\mathrm{val}} \tag{11}$$

Table 1
Multi-regional input–output table of a country with n regions.

		Intermediate use	Final use		Import	Total output
		Region 1 … region n	Region 1 … region n	Export		
Intermediate input	Region 1 … Region n	x^{rs}	y^{rs}	e^r	m^r	x^r
Added value		v^s				
Total input		x^s				

Where x^{rs} refers to the output in region r to satisfy the demand in region s; y^{rs} is the consumption demand (including the consumption of government, urban and rural residents, capital formation and changes in inventories) of region s for region r's products. e^r and m^r stand for exports and imports respectively in region r; x^r is the total output in region r. v^s refers to the added value in region s, and x^s is the total input in region s.
Source: author's own compilation.

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3. Data sources

The main data sources used in this study to calculate CEAVC were the 1997 and 2007 Chinese multiregional I/O tables (CMRIO) and the database of Chinese provincial energy use and carbon emissions. The 1997 CMRIO, compiled by the China State Information Center in 2005 (State Information Center of China, 2005), and the 2007 CMRIO, finished by the Key Laboratory of Regional Sustainable Development Modeling (China Academy Science in 2012, see Liu et al., 2012), were used. Environment data were calculated from the combustion of fuels and industrial processes by the Intergovernmental Panel on Climate Change reference approach (IPCC, 2006). To calculate carbon emissions, 18 types of combustion of fuels and industrial processes were considered in this study. Fuel data and cement output for 30 provinces were also collected from the China Energy Statistical Yearbooks of the target years. The average low calorific values contained in the appendix of China Energy Statistical Yearbooks were adopted, which are complemented by the IPCC (2006) Guidelines in case the values of any type of energy were unavailable in the China Energy Statistical sources. The potential carbon emission factors by energy use were considered as, by default, the values in IPCC (2006) Guidelines. Oxidation rate was generally valued at 1. However, considering the efficiency of energy use in China and also according to other studies (Fan et al., 2007), the oxidation rates by the different energy types varied between 0.98 and 0.995.

Eight sub-national main regions, as shown in Fig. 1, were artificially divided within China except Tibet, Hong Kong, Macau and Taiwan to correspond with that of CMRIO: Northeast (NE, including Heilongjiang, Jilin, Liaoning), Beijing–Tianjin (JJ, Beijing, Tianjin), North Coast (NC, Hebei, Shandong), East Coast (EC, Shanghai, Zhejiang, Jiangsu), Middle region (MR, Henan, Shanxi, Anhui, Hunan, Hubei, Jiangxi), South Coast (SC, Guangdong, Fujian, Hainan), Northwest (NW, Inner Mongolia, Shannxi, Gansu, Ningxia, Qinghai, Xinjiang), and Southwest (Sichuan, Chongqing, Yunnan, Guizhou, Guangxi), see Fig. 1. Provinces in every region that are adjacent to each other almost have similar industrial structure and economic characteristics, as shown in Table 2.

4. Results

4.1. PBEs and regional economic development

According to the regional total amount of direct carbon emissions (PBE), GDP, and the total output in 1997 and 2007, the regional direct carbon emission factors and per capita GDP could be obtained. The results are shown in Table 3.

The results indicate two conditions. First, China's direct carbon emissions mainly came from central and coastal areas, while the northwest region was the area with the fastest growing emissions. Based on the PBE results, the middle region, north coastal, east coastal and northeast regions all showed high figures for PBE in 1997 and 2007. Comparison of the regional growth rates of PBE between 1997 and 2007 reveal that all other regions, excluding Beijing–Tianjin and northeast regions, exhibited high growth rates (>75%), with the northwest area being the fastest growing (145.4%), followed by the north coast (133.6%) and the east coast (115.7%). Second, the regional direct carbon emissions factor was inversely proportional to the regional economic development. Fig. 2 highlights this inverse relationship between GDP per capita and carbon

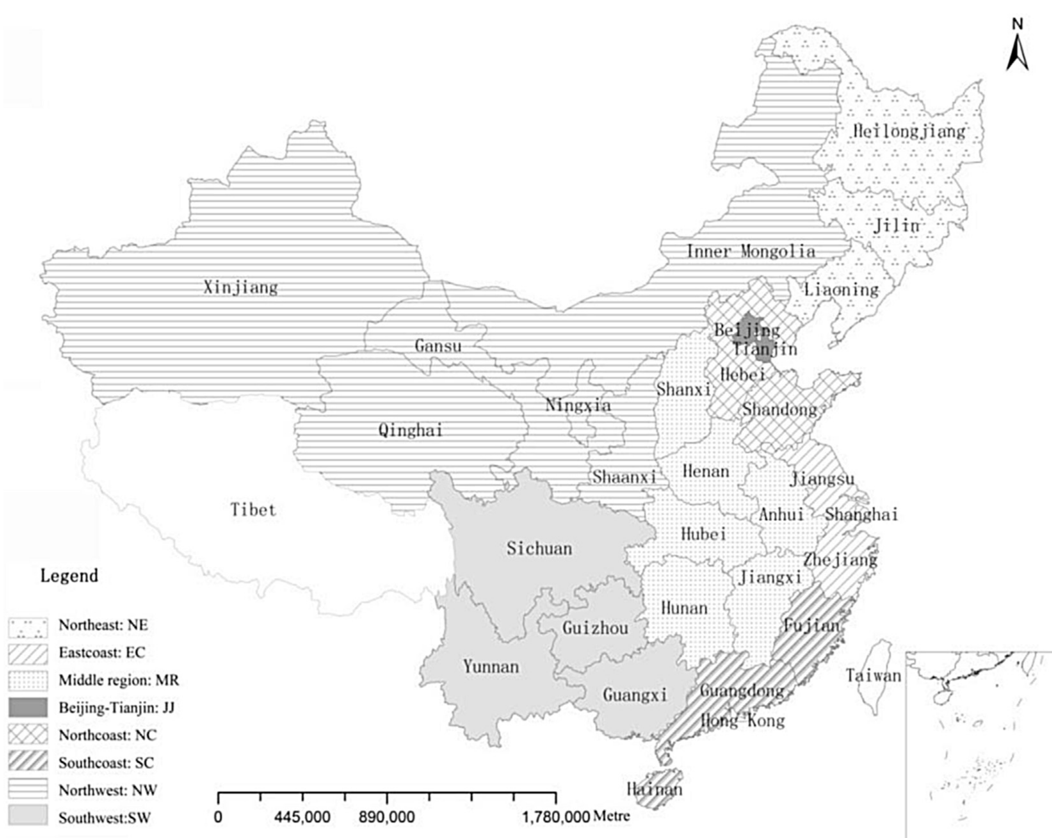

Fig. 1. Eight sub-regions of China.
Source: author's own drawing. Note: Tibet, Hong Kong, Macau and Taiwan are not included in the research scope of this paper.

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Table 2
Industrial structure and economic characteristics within and across regions in 2007.

Regions	Provinces	Industrial structure			GDP per capita dollar	Economic characteristics
		Primary industry	Secondary industry	Tertiary industry		
Beijing–Tianjin	Beijing	1.0%	25.5%	73.5%	7990	Innovative, service, developed
	Tianjin	2.1%	55.1%	42.8%	6378	
North Coast	Hebei	13.3%	52.9%	33.8%	2614	Heavy industrialized, export-oriented
	Shandong	9.7%	56.8%	33.4%	3670	
Northeast	Liaoning	10.2%	49.7%	40.2%	3464	Energy intensity, heavy industrialized
	Jilin	14.8%	46.8%	38.3%	2577	
	Heilongjiang	12.9%	52.0%	35.1%	2470	
East Coast	Shanghai	0.8%	44.6%	54.6%	8248	Manufacturing, export-oriented, developed
	Jiangsu	7.0%	55.6%	37.4%	4499	
	Zhejiang	5.3%	54.1%	40.6%	4876	
Middle region	Anhui	16.3%	45.8%	37.9%	1601	Agricultural, energy intensity, developing,
	Henan	14.8%	55.2%	30.1%	2129	
	Jiangxi	15.6%	51.3%	33.1%	1771	
	Shanxi	5.2%	57.3%	37.5%	2367	
	Hubei	14.8%	44.4%	40.8%	2179	
	Hunan	17.2%	42.1%	40.6%	1977	
South Coast	Guangdong	5.3%	50.4%	44.3%	4424	Export-oriented, superior location
	Fujian	10.8%	48.4%	40.8%	3401	
	Hainan	28.8%	29.0%	42.2%	1984	
Northwest	Inner Mongolia	11.9%	49.7%	38.4%	3526	Drought, energy supplier, sparsely populated
	Shaanxi	10.3%	51.9%	37.8%	2067	
	Gansu	14.3%	47.3%	38.4%	1411	
	Qinghai	10.5%	52.6%	37.0%	1929	
	Ningxia	10.7%	49.5%	39.8%	2013	
	Xinjiang	17.8%	46.8%	35.4%	2260	
Southwest	Guangxi	21.3%	41.6%	37.0%	1632	Mountainous, non-ferrous metal mining, poverty
	Chongqing	10.3%	50.7%	39.0%	2211	
	Sichuan	19.2%	44.0%	36.7%	1723	
	Guizhou	15.5%	39.0%	45.5%	1047	
	Yunnan	17.5%	42.7%	39.7%	1410	

Source: China Statistical Yearbook.

emissions factors in China and indicates that developed regions, such as Beijing–Tianjin and the southeast coastal areas, generally have low carbon emission factors. Conversely, developing regions, such as the northeast and the midwest regions, have high carbon emission factors.

4.2. VBEs and carbon emissions embodied in the value-added chain

4.2.1. VBE and added value

Comparison of VBE in Table 4 and PBE in Table 3 shows that the differences between PBE and VBE are not significant in any region. The rates of the differences between PBEs and CBEs to PBEs are all within the range of ±15%. This result indicates that most of the carbon emissions embodied in added value for each region occurred intra-regionally. However, the growth rate of VBEs at regional level reveals large variations. Between 1997 and 2007, the northwest region exhibited the fastest growth rate (2.61-fold) of VBEs while experiencing a fast economic growth rate (4.25-fold at current prices, hereinafter). By contrast, the Beijing–Tianjin region had the lowest growth rate of VBEs (1.53-fold) but showed the fastest growth rate of added value (4.62-fold). The implication of these differences is that the environmental impact of the economic growth in the northwest area is much higher than that in the Beijing–Tianjin region, mainly because the economic growth in the northwest region is mostly caused by mining and manufacturing (In 2007, the share of mining and manufacturing in GDP in

Table 3
Regional carbon emissions and economic development in China.

	PBE		Total output		Direct emissions factor		GDP		GDP per capita	
	MtC		10^9 CNY		tC/10^6 CNY		10^9 CNY		10^3 CNY	
	1997	2007	1997	2007	1997	2007	1997	2007	1997	2007
NE	134.09	187.14	1947	6072	68.859	30.818	765	2337	7.270	21.538
JJ	38.76	52.31	942	4309	41.146	12.140	305	1440	13.910	52.415
NC	116.80	272.83	2849	12,089	40.990	22.569	1060	3968	6.926	24.326
EC	113.68	245.20	4625	19,129	24.577	12.818	1468	5671	11.257	38.995
SC	72.84	136.19	2976	12,586	24.480	10.821	1073	4156	9.684	29.951
MR	185.97	364.36	3498	13,340	53.169	27.313	1639	5204	4.682	14.745
NW	81.39	199.73	1122	4561	72.509	43.795	467	1946	4.190	16.176
SW	95.99	168.89	2024	6787	47.418	24.886	920	2841	3.825	11.705
Nation	839.52	1626.65	19,984	78,873	42.009	20.624	7696	27,562	6.291	21.215
Coefficient of variation	0.421	0.460	0.495	0.533	0.384	0.486	0.474	0.448	0.471	0.526

Note: MtC- Million metric ton of carbon, CNY- Chinese Yuan at current price, similarly hereinafter.
Source: author's own calculation.

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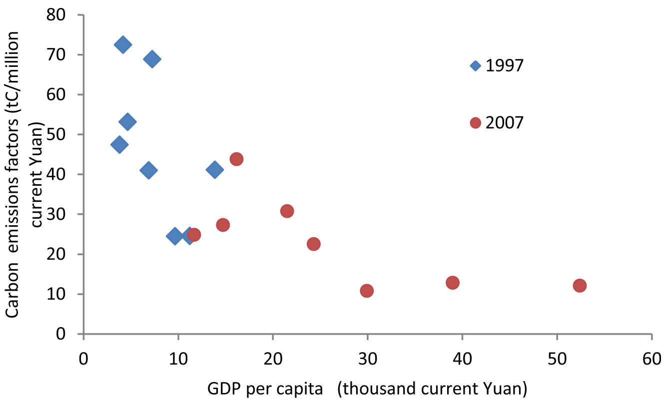

Fig. 2. Relationship between GDP per capita and carbon emissions factors in China in 1997 and 2007.
Source: author's own calculation.

northwest area was 43.6%, which was far higher than that in Beijing–Tianjin region, by 32.9%). The source of economic growth of the Beijing–Tianjin region is dominated by service industries (In 2007, the percentage of service in GDP in Beijing–Tianjin was 61.0%, compared with 35.9% in the northwest area).

4.2.2. Full emissions intensity (FEI) and direct emissions intensity (DEI)

Carbon emissions intensity broadly refers to the ratio of carbon emissions to GDP. This concept is typically understood as the production-based emissions of the unit of GDP, i.e., DEI. In this paper, we introduce the concept of FEI by dividing VBE by the value added to express the embodied carbon emissions of the unit of GDP. FEI could reflect the full environmental impact (including direct and embodied impacts) of regional economic growth rather than purely superficial impact.

No significant changes were observed in the comparison of the orders by regional FEIs and DEIs. Hence, regions with a relatively large DEI tend also to have a high FEI. For example, the northwest, northeast, north coastal and middle regions showed high figures for both FEI and DEI. However, when these regions are ranked by the rate of change of DEI and FEI in 1997 and 2007, the results vary. For example, the region with the slowest decreasing DEI rate was the north coastal area (39.4%), but its decrease of FEI rate (45.79%) was not the slowest among all the regions. The slowest region in terms of FEI decrease was the northwest area (38.46%), which ranked second last in terms of DEI decrease rate. Although the leading regions of FEI and DEI decrease were both in the Beijing–Tianjin area, the difference between DEI decrease rate (70.76%) and FEI decrease rate (66.81%) in Beijing–Tianjin area was almost at 4%.

4.2.3. Regional differences

The change in the coefficient of variation (Table 4) for every indicator shows that regional differences in carbon emissions in China between 1997 and 2007 were expanding. In line with the previously discussed increasing regional gap in PBE, regional difference in VBE was also expanding. With regard to carbon intensity, whether FEI or DEI, regional differences were expanding as well. This shows that regions with higher carbon intensity, such as the northwest, had lower decreasing rates of carbon intensity, while regions with lower carbon intensity, such as Beijing–Tianjin and the south coast region, experienced a more rapid decline in carbon intensity. In other words, economic growth in regions with high carbon intensity was more dependent on energy-intensive industries than areas with lower carbon intensity.

4.2.4. Carbon embodied in the value-added chain (CEAVC)

The results showed that the gross scale of inter-regional flow of CEAVCs in 1997 was only 168 million tons of carbon, accounting for 20.03% of the national carbon emissions. This value then increased to 367 million tons, which accounted for 22.56% of gross carbon emissions in 2007. On close examination of each pair flux of CEAVC between any two regions, all of them increased between 1997 and 2007. For example, the flux of CEAVC from the Middle region to the east coast was 18.8 million tons of carbon in 2007, which increased by 80% since 1997 (10.45 million tons of carbon). This rapid increase of CEAVC flows could be explained by the increasingly tighter regional production linkages and deeper interdependence of the regional economies.

However, the regional net outflows of CEAVC (Table 4) obviously decreased during 1997–2007. For example, the gross carbon quantity of positive net outflow shown in Table 4 (including net outflow of northeast, Beijing–Tianjin, northwest, and southwest areas in 1997 and those of northwest, east coastal, northwest and southwest areas in 2007) decreased from 28.84 million tons in 1997 to 20.74 million tons in 2007, which represented an overall decrease of 28.09%. At the regional level, the net outflows of CEAVC in some region also experienced a dramatic decline. For example, the net outflows of the northeast region showed a significant decline from 15.18 million tons in 1997 to 1.36 million tons in 2007. The net transfer of CEAVC into the north coastal area decreased

Table 4
Regional VBE in China.

	VBE		Added-value		Net outflow		FEI[a]		DEI[a]	
	MtC		10^9 CNY		MtC		tC/10^3 CNY		tC/10^3 CNY	
	1997	2007	1997	2007	1997	2007	1997	2007	1997	2007
NE	118.91	185.78	685.39	2316.85	15.18	1.36	17.35	8.02	19.56	8.08
JJ	37.86	58.01	316.06	1458.91	0.90	−5.70	11.98	3.98	12.26	3.59
NC	134.34	280.74	1021.09	3936.12	−17.54	−7.91	13.16	7.13	11.44	6.93
EC	114.92	239.73	1377.30	5719.26	−1.24	5.47	8.34	4.19	8.25	4.29
SC	75.44	137.4	992.63	4098.35	−2.60	−1.21	7.60	3.35	7.34	3.32
MR	193.42	370.28	1324.91	5201.74	−7.45	−5.92	14.60	7.12	14.04	7.00
NW	73.23	191.45	468.25	1989.13	8.16	8.28	15.64	9.62	17.38	10.04
SW	91.39	163.27	849.48	2757.96	4.60	5.62	10.76	5.92	11.30	6.12
Gross/national average	839.51	1626.66	7035.12	27478.33	0.00	0.00	11.93	5.92	11.93	5.92
Coefficient of variation	0.449	0.465	0.431	0.450	–	–	0.277	0.357	0.33	0.379

[a] FEI: full emissions intensity (full carbon emissions per unit of added value). DEI: direct emissions intensity (direct carbon emissions per unit of added value).
Source: the data source of added value is drawn from the MRIO model, and is slightly different compared with the GDP from the China Statistical Yearbook.

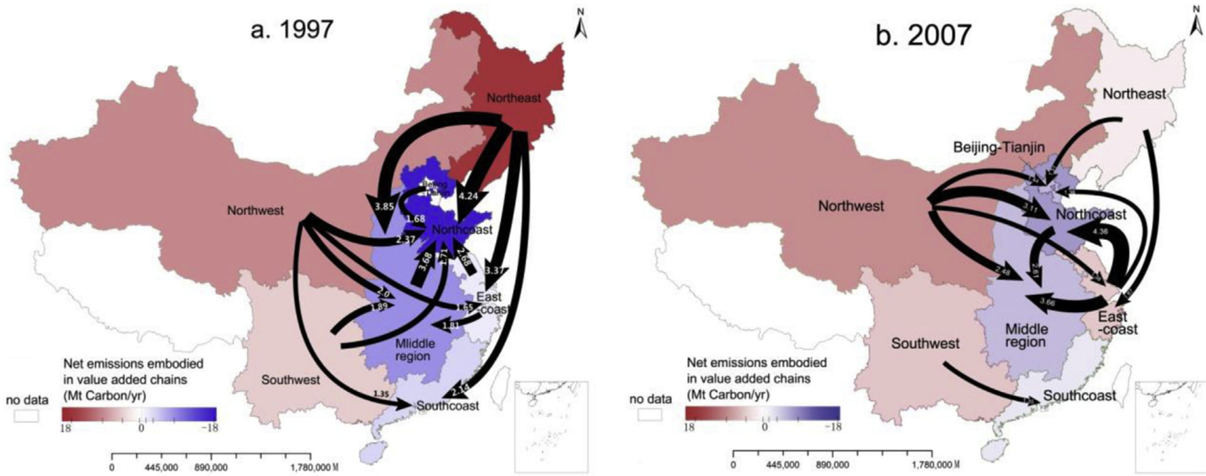

Fig. 3. Carbon emissions embodied in value added chains in China in 1997, 2007.
Source: author's own calculation.

from 17.54 million tons to 7.91 million tons. Furthermore, Fig. 3 shows largest interregional net fluxes (gross) of emissions embodied in value added chain (megatonnes of Carbon per year) among net exporting regions (red (in the web version)) and net importing regions (blue (in the web version)), the data presented in Fig. 3 reveal that most of the net flows of CEAVC between any two regions declined between 1997 and 2007.

The transfer direction also experienced some changes. The most significant change was that the main net carbon outflow region changed from the northeast to the northwest region, which was mainly caused by the implementation of the western development strategy[1] in China. Since 1949, the northeast region had been the most important heavy industry products center in China. After political reform and the opening up of China's economic borders in 1980s,[2] the northeast region still played its role, but with decrease importance. At the end of the 20th century, the implementation of the western development strategy and the reform of state-owned enterprises further accelerated the decline exhibited by the northeast region and promoted the northwest region as the prime energy supplier in China. Thus, the changes in the Chinese regional development are a key in determining the spatial change of inter-regional net carbon flows embodied in value added chains. We also could find the role of east coastal change from net domestic import to net domestic export of emissions, as well as the role of Beijing–Tianjin from net domestic export to net domestic import of emissions. These changes partly reflect the dramatic industrial structure changes in the said regions. The northwest region has become to the largest energy supplier in China, while the east coast region has become the most important manufacturing center locally and worldwide, and Beijing–Tianjin has an innovative and service oriented industrial structure. Table 2 demonstrates that the proportion of tertiary industry in GDP in Beijing is far higher than that in Jiangsu, Zhejiang and Shanghai. A survey on enterprises in Yangtze Delta in 2007 has indicated that more than 80% of the manufacturers are original equipment manufacturers, whereas 18.3% are original design manufacturers (Li, 2009). This survey showed the reliance of Yangtze Delta on simple processing and assembling for trade. This reliance on mostly low-end and low added-value manufacturing is one of the main reasons of the striking shifts in the role of east coastal region.

Carbon emissions embodied in the inter-regional value added chain may reflect the impact of the economic growth of one region on the carbon emissions of another region and reveal thus the regional inequality between economic development and environmental pollution. The results presented so far indicate that this inequality was reduced in China between 1997 and 2007 potentially because of the more even growth of regional economies. This phenomenon could be observed from the decline of the coefficient of variation of regional GDPs from 0.474 to 0.448 because of the rapid development of less industrialized areas, such as northwest and middle regions between 1997 and 2007. The rising prices of energy resources and the strategy of western development implemented in the late 20th century were highly conducive to the economic growth of less-developed regions. This implementation specifically helped the industries of the western region in China, particularly in the northwest area, to develop rapidly. Between 1997 and 2007, the total industrial output of the northwest region increased by 3.43 times, which was 2.56 times higher than the national average level.[3]

Moreover, China's entire producer price index (PPI) increased by 12% during 1997–2007, with the increase in PPI specifically of the coal and petroleum industries by 74% and 179%, respectively. By contrast, the PPI of other sectors, including machinery, building materials, textiles, and paper, declined. This price change was favorable to regions that supply energy, such as the northeast and northwest regions, whereas unfavorable to regions that focus on manufacturing, such as the south coast and east coast. The redistribution of value among sectors may be considered as one of the root causes of the shrinking of inter-regional net CEAVC flows.

[1] The western development strategy in China is a policy adopted for the western regions covers 6 provinces (Gansu, Guizhou, Qinghai, Shaanxi, Sichuan, and Yunnan), 5 autonomous regions (Guangxi, Inner Mongolia, Ningxia, Tibet, and Xinjiang), and 1 municipality (Chongqing). The main components of the strategy include the development of infrastructure, enticement of foreign investment, increased efforts on ecological protection (such as reforestation), promotion of education, and retention of talent flowing to richer provinces.

[2] Since 1979, China has pursued a policy of reform and opening to the outside world, a policy which was initiated by Deng Xiaoping. Major efforts have been made to readjust the economic structure, and reform the economic and political systems, involved the decollectivization of agriculture, the opening up of the country to foreign investment, the permission for entrepreneurs to start-up businesses, and the privatization and contracting out of much state-owned industry, and so on.

[3] Based on current prices come from China Statistical Yearbook.

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5. Discussion

Using the distribution coefficient of MRIO, this study develops a model to account for VBEs and CEAVC. Taking China as an example, this study analyzes the VBEs and the carbon emissions embodied in value-added chains at the sub-national level based on MRIO tables for 1997 and 2007. The following main findings and policy implications were reached.

(1) The PBEs (reflecting the territorial direct carbon emissions) of each region experienced a rapid increase during 1997–2007, with the northwest region as the fastest growing area. From the start of the implementation of the western development strategy, Inner Mongolia, Shaanxi and other provinces in the northwest region of China have gradually become important energy-supplying bases. Nevertheless, the northwest region of China remained as the area with the lowest energy efficiency and highest energy consumption per unit of output. Large-scale energy exploration in these areas may have brought them a significant amount of revenue and rapid urban development, but may have also created challenges including ecological damage, a single industrial structure, and slow resident income growth. Therefore, while extracting energy and other resources in the northwest territories, the local government should pay attention to policies that help to avoid ecological damage such as that experienced in traditional energy-intensive areas. These policies should also focus on how to extend the industrial chain based on energy extraction to achieve continuous development, how to increase employment and improve household incomes, and how to improve the technology level and efficiency of the use of energy resources.

In addition, the regional direct carbon emission factor is found to be inversely proportional to regional economic development. Developed regions generally have a good industrial structure, higher energy-use technology, and low carbon emissions level per unit of output. Conversely, regions with a low level of economic development generally contain low-level manufacturing industries, a larger proportion of energy and raw material industries, and low energy-use technology, resulting in high carbon emissions per unit of output. The expansion of regional differences in direct carbon emissions factors with increasing gap between regional per capita GDP during 1997–2007 also partly reflect the relationship between emissions and GDP. According to the theoretical curve of environmental Kuznets in carbon emissions, the rapid growth of carbon intensity in the take-off stage of less-developed region and the enlargement of regional differences in carbon emissions are seemingly inevitable. So, the industrial development in western China initiated by western development strategy may also be the important reason behind high carbon emissions intensity in West China. Therefore, narrowing the regional gaps between economic growth and carbon emissions by adjusting industrial structure and improving energy utilization technology in less-developed areas is an urgent challenge for the central government.

(2) VBEs refer to the full carbon emissions caused by regional economic growth. The transfer of carbon emissions embodied in value-added chains could reflect the impact of the economic growth of one region on the carbon emissions of another region, and reveal the regional inequality between economic development and environmental pollution. Two key conclusions were reached during the examination of VBEs.

First, when FEI based on VBE was used to measure the environmental impact of regional economic growth in China, the results differed from that when DEI was used. As mentioned in the previous section, the intensity of carbon emissions has been an important constraint indicator of the regional development in China, Using FEI is arguably wiser than using DEI to assess the optimum carbon reduction targets for the local government in China, because the inter-regional transfer of polluting industries could be avoided and the overall carbon reduction goal is attained.

Second, the economic relationship among sub-national regions in China has tightened between 1997 and 2007, as reflected by the increased proportion of transferred carbon emissions embodied in value-added chains to national total carbon emissions. However, the scale of inter-regional net transfers of carbon emissions remained low and showed a declining trend during 1997–2007, with the northwest region becoming the main net transfer-out region instead of the northeast region. This finding indicates that the economic status of China has grown even among sub-national regions. In other words, the regional differences in total GDP have decreased, and the regional inequality between economic growth and environmental pollution based on carbon emissions is narrowing. The sharp increase in resource prices and the implementation of the western development strategy at the end of the 20th century may be the principal drivers behind this decreasing regional inequality. Nevertheless, this inequality persists, i.e., the northwest and northeast regions still “export” carbon for economic growth to other regions such as Beijing–Tianjin and the south coast region, so, the northwest and northeast regions pay high environmental costs to develop their economies. This inequality is not only harmful to the environment protection in carbon “export” regions which is considered vulnerable, but also not conducive to the mandated carbon emissions reduction target in China because the northwest and northeast regions generally have low industrial technology and consequent higher carbon emissions to gain one unit GDP. To address this problem, this study recommends that the Chinese government should further improve the prices of natural resources including primary energy, iron ore, water and so on, and promote the development quality of less-developed regions. First, resources prices may be improved to diminish environment inequality between resources-supplying regions and developed regions and provide resource-rich regions with high capital to repair destroyed environment. Measures, such as improving resource taxes, introduction of environmental taxes, and reforming resource price mechanism, should be considered. Second, simple industrial structure dominated by energy and raw material production, as well as low production technology, may be considered as the reasons behind high carbon intensity and domestic emissions exporter in less-developed regions, such as the northwest and northeast regions. Thus, measures such as adjusting industrial structures by extending the downstream sectors and improving manufacturing technology by updating production equipment may be efficient ways to promote development quality in less-developed regions.

6. Conclusions

With China's increasing participation in global production chains and constant economic development, the country's inter-regional economic ties have grown closer. Transferred carbon emissions embodied in regional value-added chains, however, have rapidly expanded. This study has revealed that the absolute values of inter-regional net transferred carbon emissions embodied in value-added chains during 1997–2007 were small and showed a declining trend. Less-developed regions had a net outflow of carbon emissions. Therefore, regional inequality between economic growth and carbon emissions pollution was reduced during 1997–2007, although the emissions embodied in regional value-added chains had increased because of the growing proximity of inter-regional economic link in China. However, this inequality still exists at present, and less-developed regions are in less favorable positions. This study recommends that government policies should be pursued especially in less-developed regions in China, to promote the quality of economic development and improve the prices of natural resources.

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